HARD PAVEMENTS

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Hard Pavements

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HARD PAVEMENTS
Parts 1-2

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NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

HARD PAVEMENTS, PART 1

HARD PAVEMENTS, PART 2

HARD PAVEMENTS

Serial 2773 A (PART 1) Edition 1

CONCRETE PAVEMENTS

INTRODUCTION

1. **Materials for Hard Pavements.**—The term *hard pavement,* or simply *pavement,* is generally applied to a high-type surfacing placed on a thoroughfare for the purpose of accommodating heavy traffic. The principal surfacings that come under the designation of hard pavements are the following: portland-cement concrete; the bituminous concretes, including sheet asphalt, various graded-stone types, natural rock asphalt, and asphalt blocks; brick, stone blocks, wood blocks, and other blocks.

2. **Pavement Foundations.**—In the case of pavements that are surfaced with materials other than concrete, it is essential to provide a good foundation or base that can properly distribute the concentrated wheel loads of vehicles over a sufficiently large area of the earth on which the foundation rests. In order to perform this function, the foundation must have sufficient strength in compression and bending. Foundations may be of the rigid type, which includes portland-cement concrete and brick or stone blocks with grout-filled joints, or of the flexible type, which includes macadam, crushed stone, gravel, and bituminous-concrete mixtures.

3. **History of Concrete Pavements.**—The first all-concrete pavement in the United States was laid in Bellefontaine, Ohio, in 1893. This pavement was laid in blocks about 5 feet square, and although the resulting numerous joints were objectionable, and unnecessary according to more recent experience, this pave-

ment has given satisfactory service. Similar experiments were made in other small cities with equally good results, and various types of all-concrete street pavement became popular. However, the real growth in the use of concrete for pavement construction arose from the demand for permanent pavements on highways, which was caused by the increased use of automobiles and the resulting fast destruction of the waterbound macadam roads. Concrete highways have been built in every state in the Union, but especially in the Middle West.

4. **Methods of Construction.**—Concrete pavements are usually constructed in one layer in which there is no distinct line between the foundation and wearing course, the construction being carried out by the so-called *one-course method*. Occasionally, the pavement is constructed by the *two-course method*, in which a concrete base is laid first and on it is afterwards deposited a concrete or cement-mortar wearing surface. In one-course work, the same high-grade materials must be used throughout the pavement, whereas in two-course work it is permissible to use for the base course an aggregate that is not so tough and hard. Where good materials can be obtained at a reasonable cost, the extra expense involved in constructing a two-course pavement generally makes a one-course pavement more economical. Therefore, a two-course road is used only where concrete materials of high quality are scarce and too expensive, and less desirable materials are abundant.

5. **Advantages of Concrete Pavements.**—There is a great divergence of opinion among engineers concerning the relative merits of the various surfacing materials for hard pavements. However, the durability of properly made concrete is now well recognized and it is conceded that the wear and tear on a concrete road surface is comparatively small. Also, a concrete surface offers little traction resistance, so that great loads can be hauled without much expenditure of energy, especially since the hoofs of horses or the tires of automobiles do not slip on the surface easily. Maintenance and repairs are relatively inexpensive. The comfort of users is enhanced by the smoothness, good appearance, noiselessness, and absence of dust.

6. **Disadvantages of Concrete Pavements.**—For best results with ordinary portland cement, concrete pavements as usually constructed should be kept closed to traffic for at least 7 to 8 days after the concrete is laid in order to allow the concrete to harden, and some engineers consider a curing period of 10 to 14 days necessary. This delay, in addition to the time consumed in construction, is the greatest disadvantage in the use of concrete, but it may be largely avoided by using a high-early-strength concrete which becomes just as strong in a few days as ordinary portland-cement concrete does in 28 days.

Concrete roads are also likely to crack into irregular areas, unless transverse and longitudinal joints are provided. The edges of cracks are constantly battered by the tires of passing trucks and in time the cracks are enlarged into chuck holes. Prompt repairs are therefore essential. The road should be gone over annually and hot bitumen should be poured into all cracks. This repair work is ordinarily done at a small cost and it constitutes the only charge for upkeep on concrete pavements besides that for taking care of the shoulders and ditches along the road.

7. **Elements Influencing Design.**—The width being given, the five chief elements to consider in the design of a concrete pavement are *thickness, crown, grade, joints,* and *reinforcement*. These are all influenced by local conditions, such as nature of soil, intensity and kind of traffic, and climate. It is not possible to reduce the influence of the various elements to hard and fast rules, and therefore practical experience forms the best guide to successful design.

DESIGN OF CONCRETE PAVEMENTS

CROSS-SECTION AND GRADE

8. **Typical Sections.**—The design and construction of cement-concrete pavements is gradually approaching a standard practice, but there is still considerable lack of uniformity in the cross-sections of pavements adopted by the various states. In Fig. 1 are shown several typical cross-sections of pavements. The cross-section in view (a) is in use in New York State, the

section in view (*b*) is employed in Ohio, the section in view (*c*) is used in California, that in view (*d*) is used in Tennessee, and that in view (*e*) is used in Pennsylvania. Of course, different widths are in use in those states, and also other details may

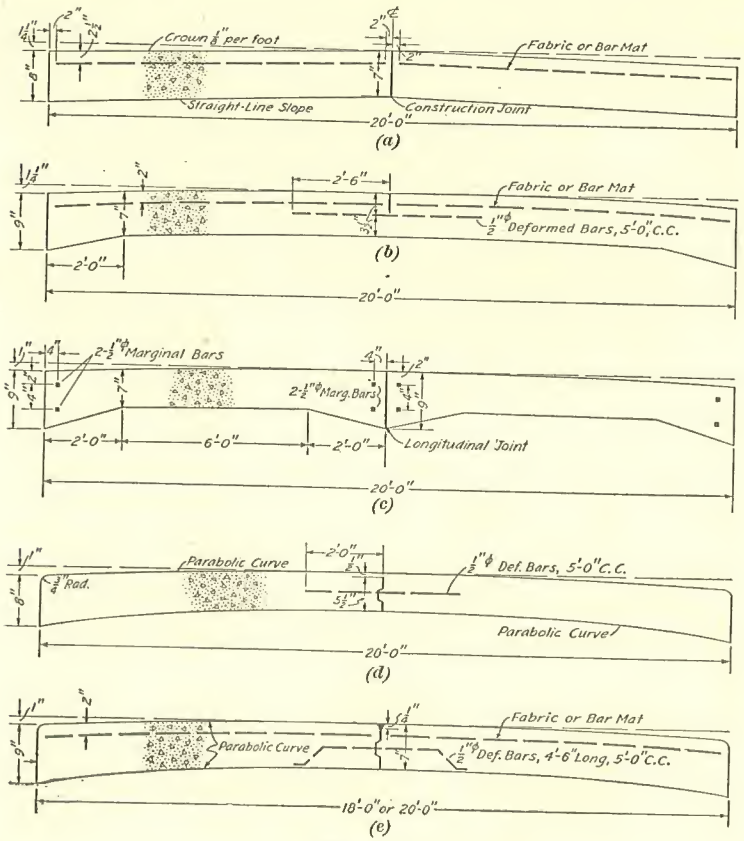


Fig. 1

vary. In each of these sections there is a longitudinal joint at the center of the road; often each half of the road is constructed separately. The thickness of the concrete is usually made greater at the edges than at the center, although a uniform thickness is used in a few states and in California the thickness is increased both at the edges and at the center. It is generally considered

advisable to provide some reinforcement, but practice differs as to the type and its amount and position in the pavement.

On each side of the concrete pavement there should be a graded shoulder 6, 8, or 10 feet wide, having a surface slope of 1 inch per foot. For most pavements earth shoulders are entirely adequate, but for dense traffic the shoulders should preferably be surfaced with a layer of bituminous-treated gravel or macadam not less than 3 inches thick. The shoulders provide parking spaces without interfering with traffic and are valuable when roadside repairs to vehicles are necessary.

9. **Thickness.**—Extensive tests on pavements and observed pavement failures indicate that the weakest parts of a pavement are at the edges, because of the small resistance provided by the soil under them. Therefore, it has become standard practice in most states to make the pavement thicker at the edges than at the center, as shown in Fig. 1 (*a*), (*b*), (*d*), and (*e*). In California, both the center and the edges are thickened, as in view (*c*), because each half of the pavement is a separate slab and supports the load coming on it without aid from the adjacent half. In some states the thickness is made uniform, but the former practice of making the pavement thicker at the center than at the edges is now obsolete.

The formula widely used for determining the thickness at the edge of a double-track concrete pavement resting on ordinary soil is

$$d=\sqrt{\frac{3W}{s}}$$

in which d = required edge thickness, in inches;
W = maximum wheel load, in pounds;
s = allowable unit stress in concrete of pavement, in pounds per square inch.

In designing highways, the maximum wheel load W is usually taken as the maximum legal load, which in most states is 8,000 pounds per rear wheel. The value of W may be assumed as 8,000 pounds for an ordinary street pavement, 10,000 pounds for one carrying many heavy loads, and 12,000 pounds for one intended exclusively for heavy trucking. The allowable flex-

ural unit stress s for the concrete in pavements is commonly assumed to be equal to one-half of the modulus of rupture. For a concrete whose ultimate compressive strength at 28 days is 3,500 pounds per square inch, the expected modulus of rupture under a steady load is about 600 pounds per square inch, and the value of s for that concrete in pavements may be taken as 300; for a 3,000-pound concrete, the value of s may be taken as 250.

At the center of a pavement which is so constructed that the parts on opposite sides of the center line are mechanically bonded together, the depth is generally made about seven-tenths of the edge thickness. The thickness is usually 8 or 9 inches at the edges and 6 or 7 inches at the center. Where the two halves of a pavement are constructed so as to act as independent slabs, the thickness at the center should be the same as at the edges, as shown in Fig. 1 (c).

10. **Crown.**—A road should have the least crown consistent with proper drainage. More crown is required on city streets than on highways, because the capacity of the gutters becomes insufficient when the crown of the street is too low. A crown of $\frac{1}{8}$ inch per foot of half width of road is sufficient for concrete highways and $\frac{3}{16}$ inch for city streets. Thus, the height of crown for a 20-foot highway should be $\frac{1}{8} \times 10 = 1\frac{1}{4}$ inches and for a 36-foot street pavement $\frac{3}{16} \times 18 = 3\frac{3}{8}$ inches.

11. **Grade.**—Concrete has been used for the pavement of roads with very steep grades. There are many concrete pavements in use at present with grades of 9, 12, and 15 per cent., and even steeper. Concrete was selected for the pavement of the road up Mill Mountain at Roanoke, Virginia, where the grade is continuous and averages 11 per cent. One concrete-paved street in Los Angeles has a grade of 32.9 per cent.

Even when a road is paved with concrete, the problem of drainage on steep grades is a difficult one, because the fast-flowing rainwater has a tendency to wash and erode the earth or macadam shoulders. This tendency may be greatly minimized by providing curbs or shallow gutters which prevent the water from discharging sidewise over the shoulders.

JOINTS

12. **Purpose of Joints.**—Concrete pavements expand and contract with changes in temperature and moisture content. Therefore, unless the pavement is designed so as to allow free movement of the slab, forces may develop in the concrete that will raise or crack it. Cracking cannot be eliminated entirely, but experience has shown that when the pavement slab is provided with transverse joints at reasonable intervals and with well-distributed reinforcement between joints, the formation of wide cracks is prevented and the number of visible cracks is materially reduced. It has also been found advantageous to divide pavements into lanes about 10 feet wide by means of longitudinal joints, as longitudinal cracking is thus reduced to a negligible amount.

There are two kinds of joints used to prevent cracking in pavements, namely, expansion joints and contraction joints. In the case of an expansion joint, which allows for both expansion and contraction, the pavement is divided into separate slabs and a space for expansion, generally filled with a compressible material, is provided between slabs. A contraction joint, however, is intended only for contraction; it is merely a vertical plane of separation, cut either entirely or partly through the pavement, and is not provided with a space for expansion.

Expansion and contraction joints are not always effective in preventing cracks, as free movement of the slab is often opposed by the friction between the bottom of the slab and the subgrade. Hence, pavements with closely spaced joints often crack excessively. Furthermore, there is evidence that reinforcement causes cracks unless transverse joints are inserted in the pavement. In general, the formation of cracks can be reduced by using a concrete of high tensile strength on a uniformly smooth subgrade, and by providing steel reinforcement and joints in the pavement slab. It is important that transverse expansion joints be perpendicular to the subgrade and to the longitudinal center line of the pavement, and that the width of such joints be uniform for their entire length and depth. Also, the joint should be so constructed as to keep out dirt or foreign material.

13. Spacing of Joints.—The usual practice is to provide transverse expansion joints spaced from 40 to 60 feet apart. In a few states it is customary to provide such joints at intervals of less than 40 feet, whereas in other states the spacing is made much larger than 60 feet. Also, some states use one or more contraction joints between every two expansion joints. In the case of city pavements, expansion joints should always be provided. The manner in which such joints are arranged at the intersection of two streets is shown in Fig. 2. The joints *ab*

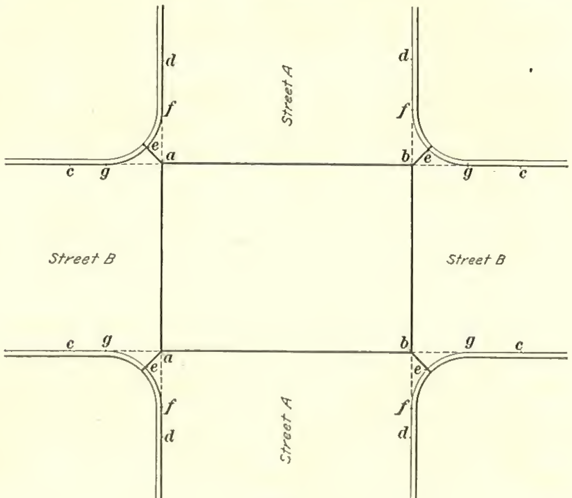


FIG. 2

that run across the street *A* are located on the prolongations of the lines of the curbs *c*, the joints *aa* and *bb* across the street *B* are located on the lines of the curbs *d*, and the short diagonal joints *ae* and *be* extend from the intersections *a* and *b* of the transverse joints to the points *e* and through the curbs.

Concrete pavements are often constructed in lanes about 10 feet wide—that is, one lane at a time—in order to reduce hindrance to traffic when good detours are not available, but the construction of the full width at one time is usually preferred because it speeds up the work and increases the efficiency of the construction force. In either case, it is customary to provide longitudinal joints in order to prevent longitudinal cracking.

In two-lane pavements, the longitudinal joint is usually on the center line. In wide streets, such joints are placed not more than 15 feet apart and often are introduced also at curbs.

14. Longitudinal Joints.—There are three general types of longitudinal joint in use : (1) contraction joints of the hinge type; (2) butt or construction joints; (3) expansion joints. Contraction joints, which may be either of the submerged type or of the dummy type, are most generally used. A submerged joint is a plane of division between adjacent slabs made by installing a deformed steel plate about $\frac{1}{32}$ inch thick. The top

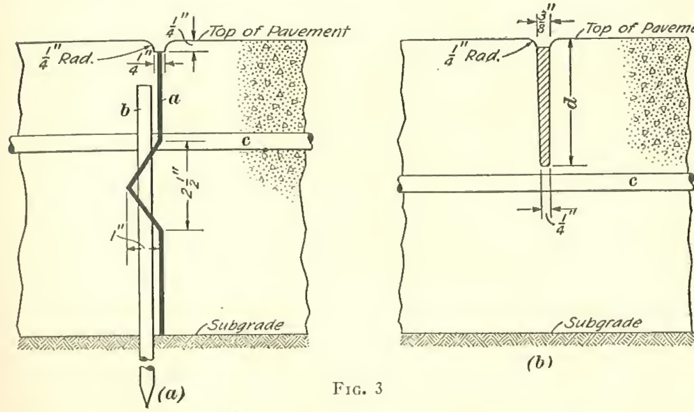


FIG. 3

of the plate is set $\frac{1}{4}$ to $\frac{1}{2}$ inch below the surface of the pavement. A groove should be left in the concrete directly over the plate and the edges should be finished with an edging tool, which is a trowel with a rounded edge; if such a groove is not provided and the plate is covered with concrete, then as contraction occurs the concrete cracks at the joint and is likely to spall worse than if the edges are rounded during construction. The dummy joint is a weakened plane that is made by forming a groove in the newly deposited concrete by means of a special device or bar and, before the pavement is opened to traffic, filling the groove with bituminous material to within $\frac{1}{4}$ inch from the top of the pavement slab.

In Fig. 3 (*a*) is shown a typical submerged longitudinal joint that is used by the Pennsylvania Department of Highways. The

plate *a* may be either bent as shown or provided with a channel-shaped deformation, as in Fig. 1 (*e*). It is held in place by means of anchor pins *b*, Fig. 3 (*a*), which are driven into the subgrade. The pins *b* are either ½-inch round rods or pressed steel channels; they are 10 to 15 inches long and are spaced 2½ feet on centers. In view (*b*) is shown a typical longitudinal dummy joint. The depth *d* of the joint is usually made about one-third of the total thickness of the slab. Tie-bars *c*, which are commonly ½ inch in diameter and 4 feet in length, are generally placed across the longitudinal joint, especially where the slab thickness at the joint is less than the edge thickness. The usual spacing of the tie-bars is 5 feet on centers.

In the case of a submerged joint, the deformation in the metal plate provides a tongue-and-groove connection between the two strips of slab. This arrangement keeps the adjacent edges of the strips at the same elevation and also transmits load from one strip to the other. With the dummy joint, the concrete below the groove cracks, but the roughness of the surfaces in contact serves to make the two strips move together vertically. In both cases, however, it is necessary to provide tie-bars in order to prevent the strips from being pulled away from each other.

Joints of the butt or construction type are simply planes of separation between adjacent slabs; they are generally used when the pavement is constructed a lane at a time. In a few states longitudinal joints are constructed as expansion joints, but usually no provision for expansion is necessary because the width of slab between longitudinal joints is not great enough. No steel tie is placed across either a construction or an expansion joint, and the thickness of the concrete at such a joint should be the same as that at the edge of the usual slab, as shown in Fig. 1 (*c*).

As alleys are generally 16 to 20 feet wide, they require a longitudinal joint at the center. This joint should be well reinforced with tie-bars so that it will not spread and let water in. Dummy joints are considered best for alleys.

15. Transverse Expansion Joints.—The usual thickness of transverse expansion joints is ½ to 1 inch, depending on the

locality and the distance between joints. Expansion joints may be of the prepared, or premolded, type, of the poured type, or of the metal type. Whichever type is used, the expansion material should extend over the full width of the pavement.

The premolded joint is made by inserting a prepared filler before the concrete is deposited. The American Concrete Institute recommends a premolded filler consisting of prepared strips of fiber matrix and bitumen, which may be either tar or asphalt of a grade that will not become soft enough to flow in hot weather nor brittle in cold weather. Tarred felt or rubber is sometimes built into the joints and allowed to remain.

Good results have also been obtained with poured joints, which are made by inserting a temporary bulkhead before the concrete is placed, removing it after the concrete has become hard enough, and pouring into the space left by the bulkhead a melted bituminous cement of such composition and consistency that it will not flow out under the summer heat. This bituminous cement will ordinarily have sufficient hardness and strength to support adequately the edges of the joints, but will yield to the expansion of the concrete in hot weather. Waterproofed sawdust is also used in poured joints.

One type of metal joint is in the form of a narrow **U**; each side of the **U** is anchored to one of the sections of slab and across the top is a piece of rust-resistant metal that opens and closes like a bellows.

16. Expansion joints are usually reinforced by means of steel dowels projecting 12 to 18 inches into each of the adjoining slabs. However, the concrete in at least one of the slabs must be prevented from adhering to the dowels, as otherwise the slabs could not expand or contract freely. This may be accomplished by using plain smooth bars that are greased or painted for half their length or by providing sleeves to receive the dowels. Also, to avoid excessive stresses in the concrete around a dowel, the hole for the dowel must not be larger in diameter than the dowel, and the dowel must be held parallel to the subgrade surface and to the longitudinal axis of the pavement. Moreover, expansion space must be provided longitudi-

nally beyond the free end of the dowel, so that the dowel will not bear against the end of the hole when the slabs expand and the joint tends to close. If the dowel is placed in a sleeve, it is prevented from going to the end of the sleeve by a plug of felt, a slight dent in the sleeve, or a wire that passes through holes on opposite sides of the sleeve. When the dowel is simply greased or painted, the end of the dowel may be covered with a short metal tube; or a cork, potato, or similar harmless compressible object may be fastened to the end of the bar.

Dowels are generally $\frac{3}{4}$ inch in diameter, but $\frac{1}{2}$-inch and $\frac{5}{8}$-inch round bars and $\frac{1}{2}$-inch square bars are also used. The spacing of dowels usually is between 12 and 30 inches. The principal function of dowels is to transfer load from one section of slab to the adjoining section and thus to maintain the adjacent ends of the two sections at practically the same level under a load. However, the effectiveness of dowels for this purpose is doubtful, especially at expansion joints, where there is a comparatively wide opening to be spanned by the dowel and a certain amount of bending is therefore produced in the dowel itself. Also, play of the dowel in the bondless socket, together with a high intensity of bearing stress between the dowel and the concrete near the joint, tends to permit movement of the dowel. If dowels are to be reasonably efficient, they should not be spaced farther than 15 inches apart. Some designers prefer to eliminate dowels entirely and to provide additional strength at slab ends by means of extra reinforcement within the slab.

17. Transverse Contraction Joints.—The use of transverse contraction joints in combination with transverse expansion joints has become quite general. These joints are, in almost all cases, of the dummy type. In some states no steel is provided across contraction joints, and in other states various methods of arranging the reinforcement are in use. However, from the standpoint of well-balanced design, it seems advisable to install slip dowels similar to those commonly employed at expansion joints.

REINFORCEMENT

18. Systems of Reinforcement.—It is not considered economical to provide steel as a true reinforcement in a concrete pavement, but reinforcing steel is effective in preventing the formation of wide cracks when the concrete contracts and free movement of the pavement on the subgrade is prevented by friction. Therefore, some reinforcement is generally advantageous in concrete streets and highways. However, reinforcement is often omitted where there is little frost or the soil is sandy. The two main types of pavement reinforcement are fabrics and bar mats; both are in the form of sheets made up of comparatively small members that run longitudinally and transversely and are joined at the intersections. The fabrics are composed of cold-drawn wires or wire-rods, whose sizes are usually expressed in terms of gage numbers and which are welded at the intersections. In the bar mats, the members are ordinary round or square reinforcing bars, whose sizes are expressed in inches of diameter or width and which are either welded or tied together at intersections.

19. Amount of Reinforcement.—The amount of main reinforcement that is required for a certain area of pavement obviously depends on the dimensions of the pavement slab and on the character of the subgrade soil. The usual practice is to specify the required weight of fabric or bar-mat reinforcement per 100 square feet of slab, but, as the distribution of the steel is an important factor, the size and spacing of the wires or bars must also be designated.

The required amount of steel is determined either arbitrarily by taking into consideration the results of experience or by proportioning the steel in each direction on the basis of the so-called *subgrade-drag theory*. When the latter method is employed the steel running longitudinally should be amply strong in tension to drag, against the resistance of subgrade friction, a slab whose length is equal to half the distance between two adjacent transverse free joints; also, sufficient steel should be provided in the transverse direction to drag a slab whose width is equal to half

the distance between two adjacent longitudinal free joints or between a longitudinal joint and the edge of the slab. On this basis, the area of steel per foot of width of pavement that is required to prevent the formation of wide cracks in the concrete may be computed by the formula

$$A_1 = \frac{l_1 wc}{2f} \qquad (1)$$

in which A_1 = cross-sectional area of steel, in square inches, per foot of width of slab;

l_1 = length of slab, in feet, between transverse joints across which no bonded steel is placed;

w = weight of slab, in pounds per square foot of surface area;

c = coefficient of friction between the concrete slab and the subgrade soil;

f = allowable tensile unit stress in reinforcement, in pounds per square inch.

Also, the amount of transverse steel per foot of length may be found by the formula

$$A_2 = \frac{l_2 wc}{2f} \qquad (2)$$

in which A_2 = cross-sectional area of steel, in square inches, per foot of length of slab;

l_2 = width of slab, in feet, between longitudinal joints across which there is no bonded steel;

w, c, and f have the same meanings as in formula 1.

The value of c is generally assumed between 1.5 and 2. For cold-drawn steel wire, the value of f is taken as from 25,000 to 30,000 pounds per square inch, and for ordinary reinforcing bars it is 18,000 pounds.

The main reinforcement is usually placed about 2 inches below the surface of the slab. This steel should not extend across any expansion or contraction joint, but should be stopped about 3 inches from the joint. A distance of 3 inches should also be left between each edge of the pavement and the edge of the sheet of steel.

There is considerable variation in the amounts of reinforcement used by the different states. A weight between 45 and 75 pounds per 100 square feet of slab seems to be ample for average conditions, provided the steel has the proper tensile properties and is adequately distributed throughout the slab. It is generally recognized that small members closely spaced are more effective than large members widely spaced. Since fabrics are usually made from smaller members than bar mats, they are often preferred. Also, the cold-drawn wire used in fabrics has higher tensile strength than billet-steel bars, and fabrics are always made with rigid electrically-welded joints, whereas tying in bar mats is often accomplished in a less effective manner.

20. **Distribution of Reinforcement.**—The main longitudinal reinforcement for concrete pavements either is distributed uniformly across the entire width of the slab for each lane or is arranged so as to provide a greater concentration of steel along the edges of the slab. However, the transverse steel is generally distributed uniformly along the slab. In the fabrics used for concrete pavements, the longitudinal members are usually spaced 6 inches apart, and the transverse members are spaced either 6 inches or 12 inches apart; where additional strength at the edges of the slab is desired, it is provided by employing several heavier members at each edge of the sheet of reinforcement. In the case of bar mats, there is a wide variation in the spacing used by the different highway departments, the average uniform spacing being 12 inches for the longitudinal bars and 20 inches for the transverse bars; a greater concentration of steel along the edges of slabs can be conveniently provided, if desired, by introducing several additional bars near those edges. The sizes of bars most commonly used for longitudinal members are, in order of preference, $\frac{3}{8}$-inch round, $\frac{1}{4}$-inch round, and $\frac{1}{2}$-inch square; and for transverse members, $\frac{1}{4}$-inch round, $\frac{3}{8}$-inch round, and $\frac{1}{2}$-inch square.

The sheets of fabric or bar-mat reinforcement are usually just wide enough for one lane of pavement. Thus, if the steel is stopped 3 inches from the edges of the pavement and the longitudinal joints, the width of each sheet would be 6 inches less

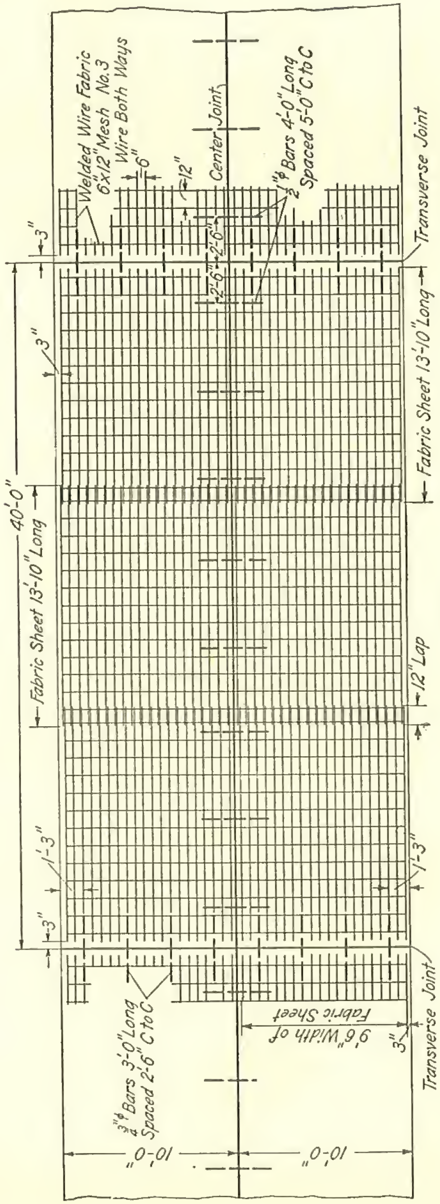


Fig. 4

than the width of the lane. Lengths of 16 feet can be readily shipped and handled, but it is preferable to limit the length of sheet to 13 or 14 feet in order that the entire sheet will be well within the reach of the boom on the concrete mixer. The exact length for any particular case is determined by the distance between transverse joints and the required lap of the sheets, which lap should generally be about equal to the spacing of the wires in the direction of the lap. A typical arrangement of wire-mesh reinforcement in a reinforced-concrete pavement is illustrated in Fig. 4. In this case, the transverse joints are 40 feet apart; the spacing of transverse wires is 12 inches, and the end lap of the sheets of reinforcement is therefore also 12 inches; and the steel is to be stopped 3 inches from the joints. If the maximum length of sheet is assumed to be about 14 feet, three sheets are required for a slab 40 feet long, and the exact length, in inches, of each sheet should be $\frac{480-2\times 3+2\times 12}{3}=166$. Hence, three sheets, each 13 feet 10 inches long, would be provided between transverse joints.

In some states, extra sheets of reinforcement are placed adjacent to each transverse joint in the slab for the purpose of either assisting the dowels or eliminating them. These sheets are laid directly over the usual slab reinforcement and extend back about 5 feet from the joint. When the extra reinforcing sheets are of the heavy-edge type, the edge with the heavy members is placed next to the joint and parallel to it.

21. Marginal, End, and Corner Bars.—Other types of reinforcement are used in some states either with or without fabrics or bar mats. These types include marginal bars, which are located near the outer edges of the roadway and sometimes also near the longitudinal joint at the center; end bars, which are placed parallel and adjacent to the transverse joints; and corner bars, which are run diagonally in the corners at the intersections of the transverse joints with the edges of the slab or the longitudinal joints.

When marginal bars are used, the common practice is to place one $\frac{3}{4}$-inch round bar about 6 inches from the slab edge and at

the center of the depth. However, in some states two ½-inch square or ⅝-inch round bars are placed in the same vertical plane, as shown in Fig. 1 (*c*). Marginal bars may be either bonded to the concrete or made bondless by painting, oiling, or greasing.

End bars and corner bars are intended to strengthen the edges of slabs. They are usually ½-inch square or ⅝-inch round. Corner bars are sometimes straight and sometimes bent to hairpin shape.

SHOULDERS AND CURBS

22. **Shoulders.**—The shoulders alongside the concrete provide additional width for passing traffic and also serve to prevent undermining of the road slab by water, which is an important feature, especially where the road is carried across a shallow depression and is subject to periodical overflow. They may be constructed of earth, gravel, broken stone, or cobblestones, the chief requirement being that the materials of the shoulders shall pack well under traffic and form a passable road surface. Gravel and stone containing some clay pack well and are preferable to clean materials; macadam makes a very suitable construction; and properly laid cobblestones are especially valuable as protection where the road is subject to inundation at certain seasons.

In some states use is also made of bituminous macadam in the construction of shoulders for main highways. Such shoulders cost more, but are advantageous where traffic is heavy because they offer a firm and durable surface that wears well and requires but little maintenance.

In building and maintaining shoulders along concrete roads, care should be taken to slope their surfaces well toward the ditches, as otherwise stagnant pools of rainwater will form and soften the foundation bed. A good sod on earth shoulders helps to prevent excessive washing during heavy rains.

23. **Curbs.**—In the Middle West and in some parts of the South where the soil is likely to scour badly, it is considered good practice to provide a raised curb along each edge of the highway pavement, in order to confine the surface drainage to the pavement proper. This curb is usually made 3 inches high and is built integral with the pavement slab. Outlets through

the curb are provided to carry the water away from the pavement. In the Eastern states, the soil is generally less likely to scour, and curbs are seldom used on rural roads.

MATERIALS FOR CONCRETE

24. **Cement.**—Portland cement is generally used in road work. It should be tested by an expert and must comply with the standard specifications for portland cements of the American Society for Testing Materials. The tested cement must be protected against moisture until it is used in concrete. In the construction of concrete pavements, it is often desirable, in order to speed up the work and open the road to traffic as soon as possible, to use concrete of high early strength. Such concrete is usually obtained by increasing the cement content and decreasing the quantity of mixing water—that is, by decreasing the water-cement ratio—and by lengthening the mixing time, but sometimes use is made of special cements. Some of these cements are quite expensive, but others do not cost more than ordinary portland cement. The use of calcium chloride in solution with the mixing water also helps secure high early strength with some cements.

25. **Water.**—The amount and quality of the mixing water used in the concrete mixture is very important. The water should be clean, that is, free from oil, acid, alkali, or vegetable matter. Furthermore, since for plastic mixes and sound aggregates the strength and other desirable qualities of the concrete are improved by reducing the net quantity of mixing water used per sack of cement, it is good practice to specify the amount of mixing water and to proportion the concrete by the water-cement-ratio method. Even when arbitrary proportions are specified, the consistency of the mix is generally controlled by specifying a slump of 1 inch to 2 inches for concrete pavements that are to be finished mechanically. Hand-finished concrete requires a slump of at least 3 inches in order to be sufficiently workable.

26. **Sand.**—The quality of the sand has a great influence on the strength of concrete. Especially good concrete is required

in roads because they are severely tested by impact and abrasion, by moisture and frost. Sand composed of hard grains, tough and durable, and carefully graded from $\frac{1}{4}$ inch downwards, with coarse particles predominating, meets the requirements of good work provided it is free from silt, clay, and organic matter; silt causes the surface to scale under traffic, and organic matter tends to weaken the concrete.

Good practice requires that the sand to be used in a concrete pavement be tested to determine its suitability. The tests of sand commonly specified are those for determining the grading; the amount of clay, loam, or silt; and the strength of cement mortar containing the given sand.

27. **Coarse Aggregate.**—The coarse aggregate should be broken stone, gravel or pebbles, or air-cooled blast-furnace slag. It must be clean, hard, tough, durable, and free from lumps of clay and flat or elongated particles. Lumps of clay wash out of the surface, leaving small holes and pockets; flat or elongated pieces are chipped by the traffic and produce much the same effect. Thus, water is admitted and the pavement is subjected to the ravages of frost. Another common source of trouble is a coating of clay or dust clinging to the stones; it prevents the binding together of the materials.

28. **Mixed Aggregates.**—In order to insure proper proportions in the concrete mixture, it is necessary that the fine and the coarse particles always be separated by screening, whether the aggregates originate in a natural deposit of bank gravel or are the product of a stone crusher, because otherwise the proportions of fine and coarse materials will vary from load to load and from day to day.

It has sometimes been proposed to remix the aggregates at the screening plant, after separation, so as to obtain a properly graded mixture. The advantage claimed is that only one kind of aggregate would have to be handled thereafter. However, experience shows that even when the different sizes are carefully mixed at first, they become separated while being transferred to storage bins, so that uniformity of mixture cannot be obtained in this manner.

PROPORTIONING PAVEMENT MIXTURES

29. **Measurement of Materials.**—In order to obtain uniformity in the strength and durability of different batches of concrete on a particular job, accurate control of the amounts of materials used in each batch is essential. There are two general methods of measuring materials, namely, by volume and by weight. If proper provision is made for the effects of bulking due to moisture and of lack of compaction, aggregates can be measured by volume with a fair degree of uniformity. Measurement by weight eliminates the necessity of considering voids between particles, and weights can be determined with much greater precision than volumes. Satisfactory equipment for weighing the ingredients of concrete has now been developed, and on all state highway work it is required that measurements of concrete materials be made by weight and not by volume. However, in specifications governing construction work, the proportions of the ingredients are expressed in terms of either dry, rodded volumes or absolute volumes. Hence, in order to prepare batches of materials on the job, it is necessary to convert volumes into weights and, where dry, rodded volumes are specified, it is also required to make proper allowance for the moisture contained in the aggregates.

30. **Arbitrary Proportioning.**—Many highway departments of states and cities specify the same quantities of water, cement, fine aggregate, and coarse aggregate for all concrete pavements, without taking into consideration differences in the grading of aggregates obtained from different sources. Thus, whether the materials are measured by weight or by volume, the quantities of the ingredients are based on arbitrary proportions rather than on a study of the particular materials to be used on a certain job. Most state highway departments that use arbitrary proportions specify a mixture, by volume, of $1:2:3\frac{1}{2}$; that is, 1 sack of cement—which is assumed to contain 1 cubic foot—to 2 cubic feet of fine aggregate and $3\frac{1}{2}$ cubic feet of coarse aggregate. However, the trend in concrete pavement work is toward the use of more scientific methods of proportioning the materials, such

as the water-cement-ratio method and the void-cement-ratio, or mortar-void, method.

31. Proportioning by Water-Cement Ratio.—It is a generally recognized principle that the strength of a workable concrete mixture is determined by the water-cement ratio, or the amount of water per sack of cement, and that the strength is increased as the quantity of water is decreased. The relative amounts of cement, fine aggregate, and coarse aggregate have an important influence on the workability of the mixture; and, for a given water-cement ratio and given aggregates, the best proportions of aggregates are determined by the requirements of workability, which are usually indicated by the so-called slump test.

In proportioning a concrete mixture by the water-cement-ratio theory, the first step is to decide on the required 28-day compressive strength and on the desired slump, and to select the water-cement ratio that, according to experience, will produce concrete having the desired strength. Then, trial batches of concrete are mixed, in which various quantities of aggregate are used, and the mixture giving the proper slump is adopted for use on the job. The quantities of aggregates used in preparing the trial batches are usually measured by dry, rodded volumes, and proportions in specifications are expressed in terms of such volumes, even though the materials on the job are measured by weight.

EXAMPLE.—The specified proportions of a mix, expressed in terms of dry, rodded volumes, are 1:2.2:3.6, and the total effective water content of the plastic concrete is to be 6 gallons per sack of cement. The weights per cubic foot of dry, rodded aggregates are: coarse, 96 pounds, and fine, 102 pounds. Also, the coarse aggregate contains 1.4 per cent. of moisture, by weight, and absorbs .5 per cent., and the fine aggregate contains 3.9 per cent. and absorbs .4 per cent. Determine the weights of (*a*) coarse aggregate, (*b*) fine aggregate, and (*c*) water that should be used per sack of cement.

SOLUTION.—(*a*) The required weight of coarse aggregate, if dry, would be

$$3.6 \times 96 = 346 \text{ lb.}$$

Since the aggregate contains 1.4 per cent. of moisture, the weight to be used in the mixture is

$$346 \times \frac{100+1.4}{100} = 351 \text{ lb. Ans.}$$

(*b*) For the fine aggregate, the required weights are:

$$\text{Dry, } 2.2 \times 102 = 224 \text{ lb.}$$

$$\text{Damp, } 224 \times \frac{100+3.9}{100} = 233 \text{ lb. Ans.}$$

(*c*) The moisture in aggregate that is effective as mixing water in the concrete is equal to the difference between the amount contained and the amount absorbed. For the coarse aggregate in this case, the amount of mixing water is 1.4−.5=.9 per cent., and for the fine aggregate it is 3.9−.4=3.5 per cent. Hence, the total amount of mixing water in the aggregates per sack of cement is

$$346 \times \frac{.9}{100} + 224 \times \frac{3.5}{100} = 3.1 + 7.8 = 10.9 \text{ lb.}$$

Since 1 gal. of water weighs 8.34 lb., the weight of 6 gal. is 50 lb. and the weight of water that must be added to the aggregates is

$$50 - 10.9 = 39.1 \text{ lb. Ans.}$$

32. Proportioning by Void-Cement Ratio.—If water is gradually added to a mixture of cement and sand, the volume of the mixture will at first increase because the water will form a film on the particles of cement and sand, and will force the particles farther apart. After all particles of cement and sand have been coated with moisture, further additions of water will inundate those particles, the films will be broken, and the total volume of the mixture will decrease until the voids between the particles are just filled with water. If still more water is added, the volume of the mixture will again increase. The quantity of water that produces the minimum volume of the mortar mixture is called the basic water content. However, to secure a plastic and workable concrete for pavement work with the coarse aggregates commonly employed, the required amount of water will be about 20 per cent. in excess of the basic water content of the mortar.

In proportioning a mixture by the void-cement ratio, one method is first to decide on the number of sacks of cement that will be used in a cubic yard of concrete. The next step is to determine the absolute volume of coarse aggregate in a cubic

yard of concrete. This absolute volume is found by dividing a certain constant—which insures a workable mix and is determined by making up trial batches of concrete—by the specific gravity of the coarse aggregate and multiplying the quotient by the weight per cubic foot of loose surface-dry coarse aggregate. It is then necessary to determine by trial the proportions of cement, sand, and water that will produce a mortar of maximum density consistent with the requirements of workability for the concrete, and also the proper amount of mortar per cubic yard of concrete, which in turn fixes the absolute volumes of fine aggregate and voids (water and air) per cubic yard of concrete. In another method, the first step is to assume a basic water content that will probably produce a concrete of the required strength and to find the corresponding void-cement ratio either by trial or by means of a suitable chart; the absolute volumes of cement, sand, and water are then taken from charts prepared for the given sand, and the absolute volume of coarse aggregate is determined as in the preceding method. When the absolute volumes of the various ingredients are known, the proportions by weight are found simply by multiplying the absolute volume of each material by its specific gravity and the weight of a cubic foot of water.

MANUFACTURE OF CONCRETE

BATCHING PLANTS

33. **Types of Plants.**—There are three general methods now in use for preparing the concrete in pavement construction. In one method, the aggregates and cement are proportioned at a central proportioning plant, and the materials are hauled in batches to the mixer at the job, where the water is added. In the second method, the concrete is mixed at a central mixing plant and transported to the subgrade in water-tight trucks. In the third method, the cement, aggregates, and water are proportioned at a central plant and the concrete is mixed, while being hauled to the job, in mixers mounted on trucks. Concrete that is mixed either at a central mixing plant or in a truck mixer is commonly known as ready-mixed concrete.

The practice of storing the aggregates and cement at the job and hauling the aggregates to the mixer in wheelbarrows is seldom advantageous in modern construction. Also, in best specifications, storage of aggregate along the subgrade is prohibited, because it prevents the proper preparation of the subgrade to receive the concrete, and results in large quantities of earth becoming mixed with the aggregates.

34. **Comparison of Methods.**—Ready-mixed concrete has been successfully employed in the construction of concrete pavements, especially for city streets. If the concrete is prepared from carefully graded aggregates, is scientifically proportioned, and is properly mixed in either a central mixing plant or a truck mixer, it can be safely hauled through a distance of several miles and delivered on the job in satisfactory condition for good construction.

On many jobs, the employment of ready-mixed concrete may greatly expedite the progress of the work. On the other hand, the finished subgrade may be considerably rutted or cut up when the hauling units for the concrete are operated over it. Such rutting may occur also when the concrete is mixed at the site and raw materials are transferred over the subgrade; but, where the concrete is delivered from the paving mixer by means of a bucket traveling over a boom, there is sufficient distance between the mixer and the concrete last laid to permit of making repairs to the subgrade without delaying the work. Most pavements, however, are constructed on comparatively firm subgrades that are not likely to be seriously affected by the operation of the hauling units. Also, in some cases arrangements may be made to pour the concrete from outside the forms, thus obviating the need for operating trucks over the finished subgrade. When a pavement is constructed in lanes, pouring from outside the forms can always be readily arranged.

35. **Handling Aggregates.**—Aggregates are generally brought to a central proportioning or mixing plant in railroad cars or barges. At the plant they are usually unloaded by a crane. They are stored most conveniently in elevated bins to which they are raised by the unloading crane either directly or

after being first placed in stock piles. If suitable pits can be dug alongside the track, the materials may be shipped in dump-bottom cars, dumped into the pits, and taken from them to the bins or stock piles by a belt conveyer or crane. Storage piles should be used only to take care of a temporary excess of material. The site for a storage pile should be cleaned of all debris and weeds and, preferably, should be rolled before any aggregate is dumped on it.

In depositing aggregate in a pile, the material should be placed in layers. If the pile is built up as a cone by dropping all the material in the center, the larger particles roll to the bottom of the pile and the various sizes of aggregate become segregated. Then batches of material taken from the edges of the pile contain an excess of coarse particles and, as a result, a porous concrete is produced. On the other hand, material from the center of the pile is too fine, and the resulting concrete is weak and scaly. A layer of material should always be left at the bottom of the pile until the end of the job, and this should be picked up with stone forks, to prevent inclusion of earth.

36. Handling Cement.—Cement may be obtained in sacks, or bags, containing 94 pounds, or approximately 1 cubic foot of material, but bulk cement is now being used to a considerable extent where the materials are proportioned at a central plant. When the ingredients of concrete are measured by volume, bulk cement cannot be used, as an excessive amount of time and care would be necessary to obtain the required degree of uniformity in measurement. Therefore, prior to the adoption of weight measurements, the cement for highway work was usually shipped in sacks. Where the aggregates are weighed at a central plant, it is a simple matter to weigh also the cement, and the use of bulk cement under such conditions is becoming common practice.

Cement is the most valuable product entering into the concrete mixture. Every effort should, therefore, be made to avoid loss of material in handling the cement and to protect it from moisture and other deteriorating influences. Cement in sacks may be stored in a warehouse or in the railroad cars on the side track. In the latter case, a water-tight shed should be provided

for storing a sufficient supply to prevent a shut-down of the plant because of a delay in the arrival of cars. The sacks should be piled in the shed in such a way that there will be some circulation of air between the piles. Bulk cement is stored in the railroad cars, in a tight container in a shed alongside the track, or in tight elevated bins.

37. All containers for bulk cement should be tight, and satisfactory covers and housing should be provided around equipment for handling the cement to protect the material from the wind and weather. Bulk cement may be transported from the mill to storage in box cars, barges, special hopper-bottom cars, special containers carried on railroad cars, or motor trucks. The material may be unloaded from box cars or barges by means of power shovels or specially designed portable pumps; or, mechanical loaders may be used to deliver the material into wheelbarrows or two-wheeled carts or buggies. Hopper-bottom cars or trucks may be unloaded by gravity, whereas railroad-car containers may be handled and dumped by means of a crane. However, the cement may be unloaded from any type of carrier by hand shoveling into carts or wheelbarrows. Devices that have been found satisfactory for raising bulk cement to elevated bins are enclosed types of vertical bucket elevators or screw elevators, enclosed belt conveyers, and pump systems with air. Also, railroad-car containers may be dumped directly into the bins and, where conditions permit, the cement may be delivered into the bins either directly from trucks or by gravity from hopper-bottom cars.

38. Equipment for Hauling Batches from Central Plant to Subgrade.—Where the materials for concrete are proportioned at a central plant and mixed at the site, the batches are generally hauled from the plant to the mixer in motor trucks. These trucks carry from one to four batches apiece, each batch being kept in a separate compartment. For contracts involving a considerable yardage of concrete and requiring hauls in excess of about 2 miles, especially in flat country, it is often advantageous to construct an industrial railroad—that is, a light narrow-gage railroad adapted for temporary use. The cars of an industrial

railroad carry containers each of which holds a batch of cement and aggregates. At the proportioning plant the containers are handled by means of a crane, and at the job they are lifted by a derrick on the mixer. Horse-drawn wagons have become practically obsolete for this work, and tractor trains travel too slowly to be economical.

Concrete that is mixed at a central plant is usually hauled to the subgrade in special open trucks, from which it can be dumped easily. The capacity of such trucks varies from 1 to 5 cubic yards. To assure easy dumping, the inside of the truck body must be kept clean. The bodies of some trucks are made **U**-shaped and those of others are **V**-shaped, but the larger trucks have flat bottoms. The best way to break the adhesion between the concrete and a flat bottom is to provide in the truck body a false front-end that starts to slide as the truck body is raised to the dumping position. Good results have been obtained with a false end that is hinged to a 3- or 4-foot section of false bottom and is fastened to the truck body by chains having enough slack to allow the false end to slide several feet. Some trucks for conveying mixed concrete are provided with agitators to stir the concrete continually.

Truck mixers are made in several sizes. When used to mix raw materials in transit, their capacities range from 1 to 5 cubic yards of concrete. However, if these mixers are used merely to haul central-mixed concrete, they will hold from 2 to 8 cubic yards, because unmixed raw materials occupy more space than mixed concrete obtained from them. Truck mixers should be capable of discharging from either side of the truck. Some types are provided with an extra tank for wash water, which is admitted to the mixing drum as soon as the concrete has been discharged; the drum is revolved slowly during the return trip to the central plant and is thus washed and kept clean for the next batch of concrete.

39. **Batching Equipment.**—When the materials are proportioned by weight, each is measured in a hopper that is hung on the levers of a scale. There is generally a separate weighing hopper and a separate scale for the cement. Sometimes there is

a separate hopper and a separate scale for each aggregate, but there may be a single hopper for all aggregates; in the case of a beam scale, a separate beam and poise is provided for each aggregate. The scales for aggregates are set directly beneath the storage bins and, where the cement also is stored in an overhead bin, the weighing equipment for that material may be placed under its bin.

Where cement is stored in railroad cars, the common practice is to construct a platform alongside the railroad track. If ready-mixed concrete is to be provided, the sacks of cement can then be trucked from the car to the mixer; and where the concrete is to be centrally proportioned, the sacks can be placed on the trucks that transport the materials to the mixer. Bulk cement in cars is usually batched by hand into two-wheeled buggies, which are weighed by a scale on the platform. The buggies can then be run directly to the mixer or emptied into the trucks according to the type of plant. In order to prevent loss of cement during the operation of dumping it from a cart into a truck, the material should be fed into a canvas *boot* that extends above the platform and reaches to the truck.

In the case of ready-mixed concrete, it is a simple matter to add the proper amount of water. At a central mixing plant, the mixer is stationary and the tank for measuring water can also be fixed in position. Truck mixers also receive their water from a stationary tank. The amount of water in the tank may, therefore, be accurately determined by the level of the water surface. The moisture on the surface of the aggregates must be included in the total amount of mixing water. However, the percentage of surface water in aggregates may be determined from time to time by test and the necessary adjustment made in the amount of water fed from the measuring tank.

40. **Layout of Central Proportioning Plant.**—In general, the three important considerations in regard to the layout of a central proportioning plant are: (1) Unloading the incoming materials and providing for their storage; (2) proportioning the materials into batches of suitable size at a rate that will keep the mixer functioning efficiently; (3) providing for the loading

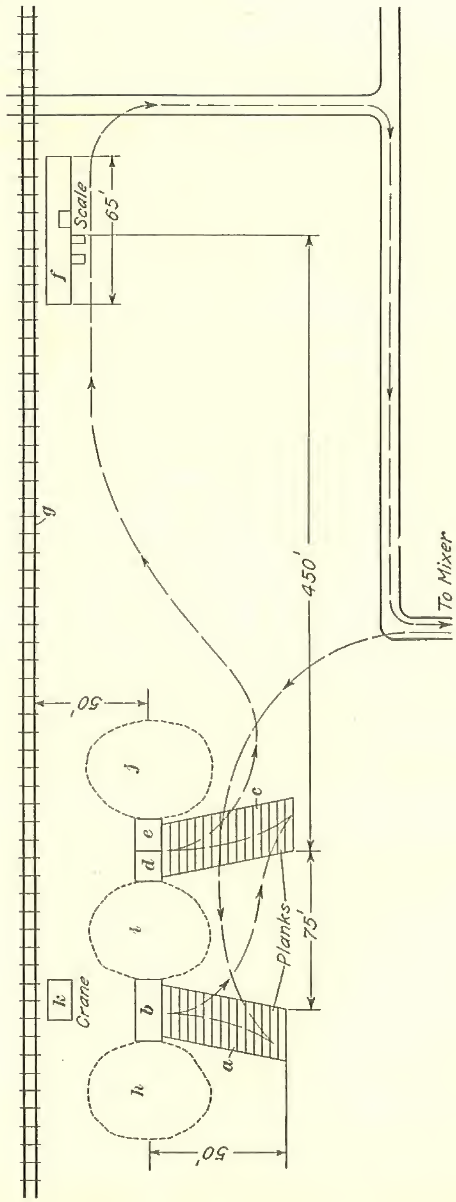


Fig. 5

of the entire batch into the hauling truck with the least possible delay and by the shortest possible route. In Fig. 5 is illustrated a good layout where the coarse aggregate is divided into two sizes—one from $\frac{1}{4}$ to $\frac{3}{4}$ inch, and the other from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches—and bulk cement is stored in the railroad cars. The route of the trucks is indicated by the curved dash lines and the arrows on them. An incoming truck goes first to the plank runway *a* and receives the proper amount of large-size coarse aggregate from the elevated bin *b*. It then proceeds to the runway *c*, where it takes on the smaller coarse aggregate from the bin *d* and the fine aggregate from the bin *e*. Time is saved if the truck is backed under each bin. After the aggregate has been loaded, the truck goes for cement to the platform *f* alongside the railroad track *g*. Stock piles of aggregate are shown at *h*, *i*, and *j*. The crane *k* for handling the aggregates may move along the space between the aggregate bins and the track.

Sacks of cement are usually laid on top of the aggregate in the trucks. For transporting bulk cement to the mixer by truck, there are three methods in general use: (1) Spreading the cement over part of the aggregate and placing the rest of the aggregate on top; (2) dumping the cement on top of all the aggregate and covering the materials with a canvas or tarpaulin; (3) placing the cement in a special container on the truck. Where the first method is used, it is best to have the aggregates in two separate bins with the cement platform between them, but some contractors load all the aggregate first, and then move part of it to the side of the truck, deposit the cement in the center, and replace the aggregate on top.

41. Ready-Mix Plant.—In the case of a central mixing plant, it is usually convenient to set the mixer above the ground so that the mixed concrete can be discharged directly into the hauling trucks, and to erect bins for the aggregates and cement at elevations considerably above that of the mixer. Equipment for measuring the materials is provided directly below each bin. The measured materials for a batch are assembled in a hopper from which they are admitted to the mixer. A typical central mixing plant is shown in Fig. 6. In this case, a belt conveyer *a*

is used to raise the aggregates to the bins *b*, and the cement is lifted to the bin *c* by means of the vertical elevator *d*. The

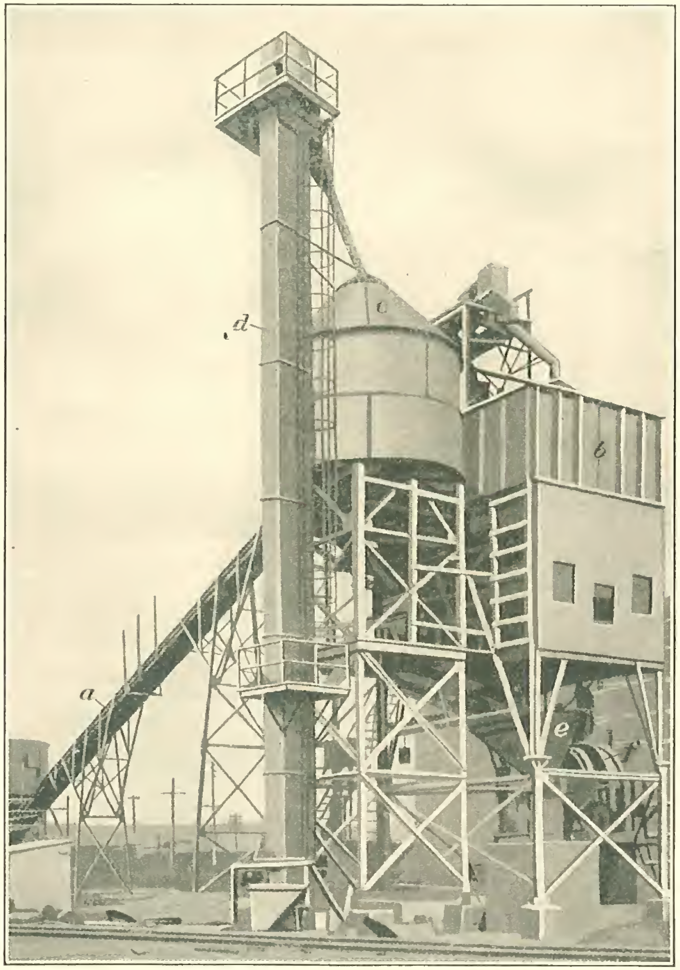


Fig. 6

measured materials are assembled in the hopper *e* and then fed into the mixer *f*. While one batch is in the mixer, the materials for the next one are being assembled in the hopper.

Where the concrete is mixed in truck mixers, the layout may be essentially the same as at a central mixing plant, but the batches are discharged from the assembling hopper into the truck mixer instead of a stationary mixer. The aggregates and cement are sometimes fed into truck mixers directly from a belt conveyer.

PAVERS

42. General Description.—The essential parts of a paving mixer, or so-called paver, that operates on the subgrade are a mixing drum in which the concrete is mixed; a skip, which

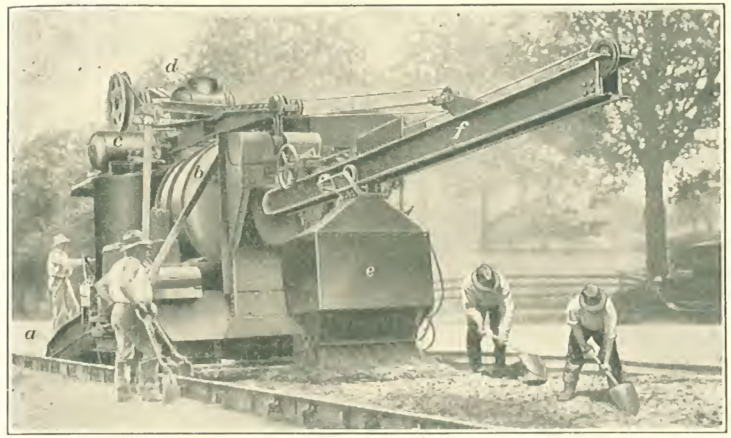


Fig. 7

receives the batches of aggregate and cement and discharges them into the mixing drum; equipment for measuring the water and feeding it into the mixing drum; a device for conveying the mixed concrete from the mixing drum to its final position on the subgrade; and equipment for moving and operating the mixer. A typical paver is shown in Fig. 7. The batch of dry materials is dumped into the skip *a* from the truck or other hauling unit, and the skip is then raised by means of cables on the paver so that the materials slide into the mixing drum *b*. The water for each batch is measured in the tank *c*, from which it flows into the drum *b*. The mixer shown in the illustration is provided with an auxiliary tank *d*, which is continually being

filled with water from the supply line for the purpose of feeding it rapidly into the measuring tank *c* when needed. The use of the auxiliary tank also permits the connections in the supply line to be changed without delaying the paver. After the materials have been mixed for the proper length of time, the concrete is discharged into the bucket *e* which travels along the boom *f*. This boom can be swung in any direction in front of the paver, and the bucket stopped and discharged at any point of its travel.

All pavers are self-propelling. Gas engines, diesel engines, or electric motors are used to furnish the power for moving and operating the machine, which is usually equipped with caterpillar traction.

43. **Details of Operation.**—The paver usually stands on a crowned and sloping subgrade and, in order to obtain accurate measurement of water, it is necessary to provide either an adjustable closed chamber, which is completely filled and emptied for each batch of concrete, or a meter that shuts off the water supply when the correct amount has passed. The water and dry materials are introduced into the mixing drum at the same time. When calcium chloride is used as an admixture in the concrete, it should be put in with the mixing water, as otherwise the mortar may harden on the inside of the drum.

When a paver is used, the capacity of its mixing drum determines the maximum rate of progress. Since the time required for mixing the concrete cannot be reduced below a certain minimum, the output can be increased only by using a larger mixer or by using more than one mixer. Manufacturers have found that a mixing drum holding 1 cubic yard of concrete is about as large as is desirable for a paver. Moreover, all batch compartments on trucks and special containers for batched material are designed for a mixer of that capacity. However, the newest pavers are provided with dual mixing drums, and in such pavers a batch of concrete is mixed for half of the required time in one drum and is then passed into the second drum where the mixing is completed. The machine is so designed that the mixing action is the same while the concrete is passing from one drum to the other as while it is all in either drum.

Some contractors use two pavers in tandem, that is, one behind the other. In this case, the concrete is mixed for part of the time in one paver and is then discharged into the skip of the other paver and the mixing is completed in that machine. However, many states prohibit this practice because concrete made according to their specifications is not wet enough to flow from the skip of the second mixer into its drum.

44. In general, longer mixing improves concrete, but practical considerations determine the time during which mixing should be continued on any particular job. Under absolutely controlled laboratory conditions, 45 seconds of thorough mixing produces satisfactory concrete. But, 1 minute should be considered the absolute minimum mixing time on paving work under usual field conditions, and in some states $1\frac{1}{4}$ or $1\frac{1}{2}$ minutes is required. Some mixers have automatic devices for indicating when the concrete has been mixed for a certain time at a certain number of revolutions, and for counting the number of batches mixed, which is a check on the number of sacks of cement used. These machines have also an automatic lock that prevents the discharge spout from releasing the contents of the drum until the concrete has been mixed the specified time.

As the efficiency of the blades in the drum is impaired if they are coated with hardened mortar, the mixer should be carefully washed each time when leaving off work. In case mortar tends to harden on the blades during the regular operation of the mixer, as it sometimes may in very hot weather and when accelerating admixtures are used, the blades can be kept clean by depositing the batch of materials in the skip in such a way that the coarse aggregate goes into the drum before the other ingredients.

The pile of material that collects under the discharge spout of the mixer should be taken up and placed in the slab as the work progresses. If this is not done frequently, the material should be shoveled to one side when the mixer is moved ahead and should not be used in the slab because it will be of various ages and will not be uniform with the remainder of the concrete.

PROVISION OF MATERIALS

45. Estimating Quantities of Materials.—The first step in estimating the quantities of cement, sand, and coarse aggregate for a stretch of concrete pavement is to determine the cross-sectional area, in square feet, of the pavement. If this area is divided by 27, the quotient is the number of cubic yards per foot length of pavement; also, if the area is multiplied by 5,280 and the product is divided by 27, the result is the number of cubic yards per mile of pavement. The next step is to estimate the quantities of materials required per cubic yard of concrete. These values depend on the proportions of ingredients, including water, used in the concrete mixture. Finally, the total volumes of the materials are found by multiplying the quantities per cubic yard of concrete by the required number of cubic yards of concrete. No allowance need be made for waste of cement; but, for the sand and coarse aggregate an allowance, based on past experience with similar methods of handling and not exceeding 10 per cent., should be made.

The amount of water required for sprinkling the subgrade, mixing concrete, and sprinkling the finished pavement depends somewhat on prevailing weather conditions, but from 25 to 30 gallons per square yard of pavement is the usual requirement.

EXAMPLE.—Determine the quantities of cement and aggregates required for a mile of the pavement shown in cross-section in Fig. 1 (*a*), if the proportions of the mix and the characteristics of the aggregates are as given in the example of Art. 31. Also, the specific gravity of the coarse aggregate is 2.62, that of the fine aggregate is 2.65, and that of the cement is 3.1; the bulking factor is 1.17 for the fine aggregate and 1.05 for the coarse aggregate. Assume a 5 per cent. allowance for waste of aggregates.

SOLUTION.—The average thickness of the pavement shown in Fig. 1 (*a*) is 7.5 in. and the width is 20 ft. Hence, the cross-sectional area is $20\times\frac{7.5}{12}=12.5$ sq. ft., and the volume per mile is $\frac{12.5\times5{,}280}{27}=2{,}444$ cu. yd. To compute the quantities of materials per cu. yd. of concrete, the absolute volumes per sack of cement are first found as follows:

Cement, $\frac{94}{3.1\times62.5}=.49$ cu. ft.

Fine aggregate, $\frac{102\times2.2}{2.65\times62.5}=1.36$ cu. ft.

Coarse aggregate, $\frac{96\times3.6}{2.65\times62.5}=2.11$ cu. ft.

Water $\frac{6}{7.5}=.80$ cu. ft.

Concrete, $.49+1.36+2.11+.80=4.76$ cu. ft.

The required quantities of materials per cu. yd. of concrete are:

Cement, $\frac{27}{4.76}=5.67$ sacks

Fine aggregate, $\frac{5.67\times2.2}{27}\times1.17=.540$ cu. yd.

Coarse aggregate, $\frac{5.67\times3.6}{27}\times1.05=.794$ cu. yd.

Therefore, the required quantities per mile of road are:

Cement, 2,444×5.67 .... =13,860 sacks
Fine aggregate, 2,444×.540 =1,320
5% allowance for waste = 66 .... 1,386 cu. yd.

Coarse aggregate, 2,444×.794=1,941
5% allowance for waste = 97 .... 2,038 cu. yd.

46. Consistency of Concrete.—The consistency of concrete for pavements should be such that the mixture will be barely workable under the strikeboard used to smooth off the surface and will hold its shape and not show any tendency to flow. Such a mixture can be properly consolidated on the roadbed and can be struck off and finished to better advantage; also, it is stronger and more uniform in texture than a wetter mixture.

Concrete that is mixed at a central plant should be rather dry and thoroughly mixed. Unless such concrete has just the right consistency, it will segregate while being hauled, but paving mixes of suitable consistency can usually be hauled satisfactorily for long distances. Even a small amount of segregation will pack the concrete in the bottom of the truck body so tightly that it will have to be shoveled or pounded out. Limestone or other absorbent aggregate should be kept wet in the storage bins or

piles so that it will not absorb moisture from the mixed concrete. The concrete will not then become too dry for finishing after being hauled, and it will not be necessary to make allowance for absorption in providing the mixing water and thus permit segregation to occur before the excess water is absorbed.

There is generally a change in the slump of concrete as time after mixing elapses. This change should be taken into consideration where ready-mixed concrete is hauled for a long distance.

47. Water Supply.—Road builders are often confronted with the difficulty of obtaining the required supply of water for concrete-pavement construction, and this matter should be investigated carefully by the engineer and contractor when making estimates. Otherwise, the quality or quantity of work done may be affected because of inadequate water supply, or the contractor may suffer a loss due to not having anticipated the need of a special pumping equipment to distribute water in the quantity required and where needed.

When the only source of water supply is several miles distant from the job, a pumping outfit designed to furnish not less than 250 gallons per minute and driven by a 5- or 6-horsepower gasoline engine usually proves the most economical and satisfactory means of assuring a dependable supply of water. If water from a stream or pond is used, care should be taken to protect the intake pipe in some manner to prevent weeds, small sticks, silt, and other objectionable material from being drawn into the pipe line. For concrete street pavements, water may frequently be obtained from fire hydrants.

The quantity of water delivered in a certain time depends upon the size of pipe and velocity of flow. Experience shows that a 3-inch pipe should be the minimum used. Pipes of smaller diameter will not deliver a sufficient quantity of water economically because of the great friction between the water and the sides of the pipe.

Unions should be placed in the pipe line about every 500 feet, so that, if it should be necessary to repair or change the location, the pipe line can readily be taken apart to remove a section. To facilitate required attachments, there should be a branch connection, called a tee, in every 200 feet of the line, and there should be a valve at each tee for a sufficient distance back of the mixer to permit sprinkling the road surface as required. From these valves water is drawn to the mixer by means of a rubber hose. Such hose should not be smaller than $1\frac{1}{2}$ inches in diameter; otherwise, it will not supply water to the mixer so rapidly as needed in most cases.

Some form of relief valve should be provided in the line so that the pipe or the pump will not be damaged by excess pressure when the pump is running but no water is being used. A fitting known as a spring relief valve has a valve controlled by a spring and may be so adjusted that the valve will open at any desired pressure. If freezing may be expected at night, drain cocks should be installed at all low points in the pipe line, and the water should be allowed to flow out to prevent bursting of the pipe. In order to shut off parts of the line for repairs or for other reasons, there should be a gate valve every 1,000 feet in the pipe line.

CONSTRUCTION OF CONCRETE PAVEMENTS

PREPARATION OF SUBGRADE

48. Sprinkling Subgrade.—Unless the subgrade is damp when the concrete is deposited, it will absorb much water from the concrete, and shrinkage cracks will form in the pavement. In order to prevent such absorption, a dry subgrade should be sprinkled with water until it will not absorb much more moisture. However, care should be taken not to wet the subgrade so much that it will become muddy. Also, the sprinkling should be done so as not to throw dust on the exposed edge of the completed concrete slab.

Light sprinkling just before the concrete is placed is of some value, but with most soils it is best to wet the subgrade the night before the concrete is to be laid. Adobe and gumbo soils are exceptions; they should be sprinkled lightly just before the concrete is laid. If they are made quite wet, they will swell and then settle again as they dry; whereas, if they are left dry, they will absorb water from the concrete, and may swell and lift the

freshly laid slab, either cracking it or producing a wavy surface. On the worst soils of this class or on loess, which is finely divided, windblown soil, some treatment of the subgrade is advisable.

49. Preparation of an Existing Roadway.—A concrete pavement may be laid directly on an old road surface. In preparing the old surface, all vegetable or other perishable matter should be removed. If in certain sections of a road it becomes necessary to place a fill on the surface of an old road, the surface should be scarified to a depth of several inches so that it can be leveled and given uniform compactness before any fresh material for filling is added. The material of the fill should be laid in layers 8 to 12 inches thick and rolled to a uniform density with an 8- or 10-ton roller, so that the fill will not settle and cause cracks in the concrete slabs. If concrete is to be laid directly on an old gravel or macadam road, the surface should be scarified and recompacted by rolling in order to make a smooth surface. This will prevent loss of mortar, which would tend to flow from the concrete into any holes or depressions in the subgrade surface, and will provide a uniformly compacted subgrade for the concrete slab.

50. Repairing Damage to Subgrade Surface.—It is generally required that every point on the subgrade surface should be within $\frac{1}{4}$ inch of its correct elevation before the concrete pavement is placed upon it. The subgrade is usually given the proper shape while the grading work is being done but, where the mixer and the trucks hauling materials operate on the subgrade, the surface is often rutted or cut up between the completion of the grading and the placing of the concrete. If the concrete is mixed on the job, the necessary repairs can be made to the subgrade by hand in the area between the completed slab and the mixer. Immediately before the concrete is placed, the subgrade should be checked with a templet.

Where ready-mixed concrete is used, it is difficult, if not impossible, to repair damage caused by the hauling units, and therefore in this case such damage to the subgrade must be prevented. If the subgrade is liable to be injured by the hauling units, the use of ready-mixed concrete may be made possible by pouring the concrete from outside the forms. Construction of the pavement in lanes always permits this method of pouring to be adopted.

SIDE FORMS

51. Introduction.—Forms for the construction of concrete pavements are almost always of steel rather than of wood; in fact, most states now prohibit the use of wooden forms in this work. A variety of highway work can be performed with a relatively inexpensive stock of steel units, and the adaptability of the same units to the various types of construction makes their use economical. Some very ingenious steel forms have been devised for road work, but in the following articles are described only simple types that are adaptable to several phases of such construction.

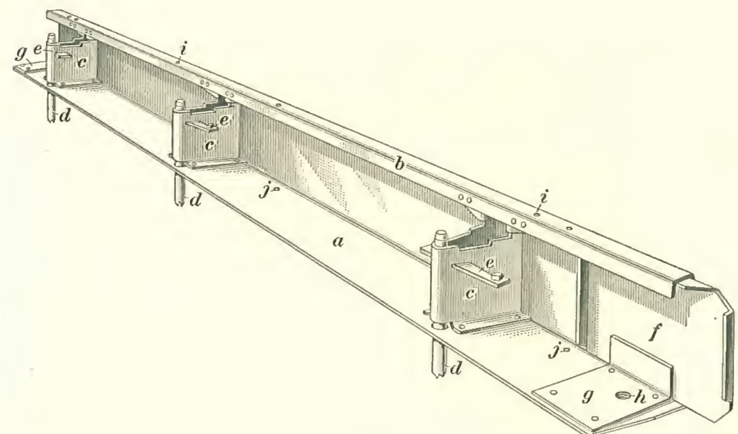


Fig 8

52. Road Rails.—Two common types of steel forms used for roadway pavements are illustrated in Figs. 8 and 9. In Fig. 8 is shown the *Dreadnaught* road form, which is manufactured by the Blaw-Knox Company, and in Fig. 9 is shown the *Armor Plate* road form, manufactured by the Heltzel Steel Form and Iron Company. Both types are of $\frac{3}{16}$-inch steel and are

made in 10-foot lengths. These forms are made in depths of 6, 7, 8, 9, 10, and 12 inches.

The form shown in Fig. 8 has either a 6-inch or an 8-inch base *a* and a top rail *b*, which may be used to support surfacing equipment. On each section are three stake pockets *c*, riveted firmly to the base and top rail. Circular 1-inch stakes *d* are fitted into these pockets for supporting the forms in a vertical position. Wedges *e* are provided at each stake to prevent slipping of the forms. At one end of the section is a lock-joint plate *f* with beveled corners; this plate locks into the adjoining end of the next section. The ends of the sections are reinforced

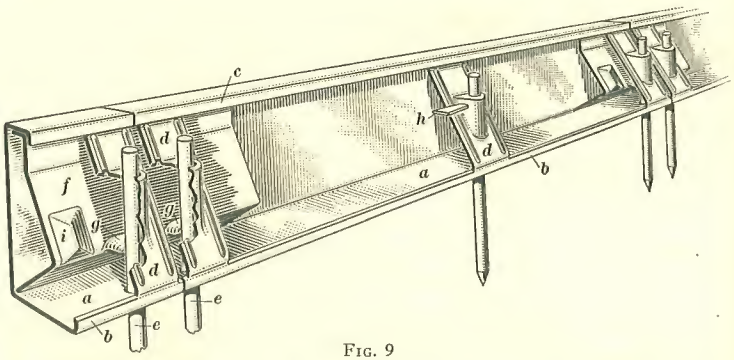


FIG. 9

by plates *g*, and holes *h* are provided for extra stakes when needed. The holes *i* in the top rail are for bolting on a lighter form for an integral curb or for bolting two road forms together. The holes *j* in the base are for bolting this form on top of wooden or metal risers.

53. The form shown in Fig. 9 has a 6-inch base *a* with a reinforcing flange *b* at the outer edge. The top rail *c* serves the same purpose as the top rail on the form in Fig. 8. There are three welded stake pockets *d* in each 10-foot section, the outer stake pockets being close to the end of the section. The stakes *e* are 1 inch in diameter and fit in specially designed holes. A sliding lock-joint plate *f* holds two adjacent sections of form together and at the same time wedges the stakes firmly in place by means of steel nubs *g*. A special driven wedge *h* is sometimes

used on the intermediate stakes. The plate *f* is released by striking the lug *i*.

54. Side Rails for Curbs and Gutters.—The usual side rail, which may be used interchangeably on separate curbs, curbs and gutters, or integral curbs, consists of a 10- or 12-foot steel plate with reinforced flanges at top and bottom. The form shown in Fig. 10 is manufactured by the Blaw-Knox Company; that manufactured by the Heltzel Company is of similar cross-section and general construction, but the methods for connecting and supporting the rails are different. The rails are made in heights from 4 to

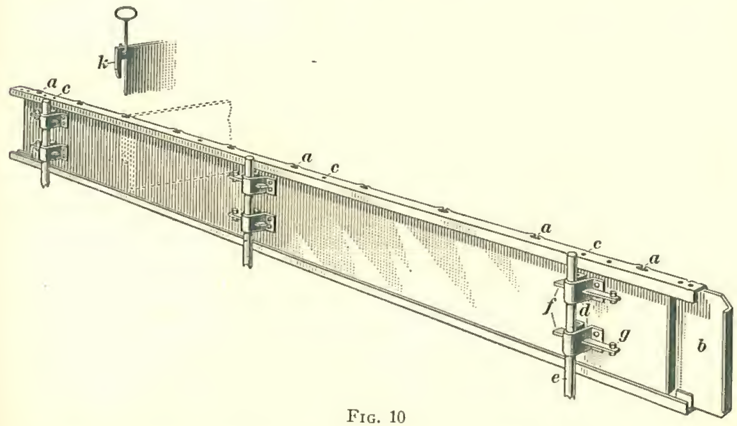


FIG. 10

24 inches. Slots are usually provided in them, as at *a*, to permit the insertion of division plates, one of which is indicated in position by dotted lines; the details at the end of the plate are shown more clearly in the sketch above the rail. These plates serve the double purpose of acting as spacers and of forming expansion joints in the concrete. Two adjacent lengths of side rail are connected at the ends by means of the special sliding plate *b*.

In the construction of curbs and gutters, the form for the back of the curb sometimes consists either of two side rails placed one on top of the other or of a side rail placed on top of a road form. Also, the form for the face of a high separate curb may consist of two side rails. Therefore, the flanges on the side rail are so made that one section can be used above another to

form a higher rail, and the holes *c* are provided in the top and bottom flanges for bolting one section to another or to a support.

55. In Fig. 10 is shown the staking system used by the Blaw-Knox Company and in Fig. 11 is illustrated the stake used by the Heltzel Company. In Fig. 10, the stake supports consist of two **U**-shaped plates *d*, which are riveted to the side rail. The stake *e* slides through the outer parts of the plates *d* and is held firmly in place by the wedges *f*. Short bolts *g* are provided at the narrow ends of the wedges here shown in order to prevent their getting disconnected from the rail section and lost.

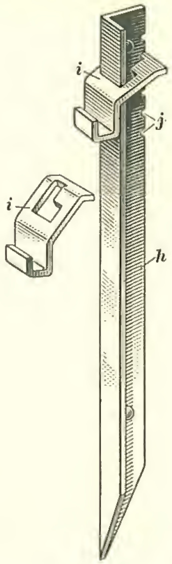


Fig. 11

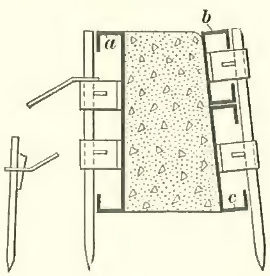


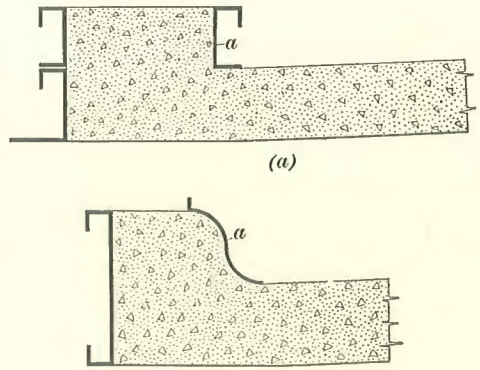
Fig. 12

In Fig. 11, the stake consists of an angle *h* that is provided with a clip *i*, which fits over the stake and under the top flange of the rail. These clips can be moved up or down, as desired, on the notches *j* in the stake, and they can thus hold the forms at any desired height.

56. Curb Forms.—When a curb is made separate from the street or gutter, the rails for both faces extend the entire height of the curb. In Fig. 12 is shown the method of setting up the Blaw-Knox side forms; a similar procedure is followed for other types of forms. The single rail *a* is generally 18 inches high and the heights of the two rails *b* and *c* are 12 inches and 6 inches,

respectively. Usually, the side facing the roadway is sloped but, if desired, the forms for both faces may be set without slope.

Where the curb is integral, or poured monolithically with the street paving, a set of forms like that shown in Fig. 13 is generally used. The inner rail *a* may be either straight, as in view (*a*), or curved, as in view (*b*). It is also possible to obtain a rail *a* that slopes outwards toward the top of the curb. The inner rail is held in place by horizontals extending over both curb rails.



(b)
Fig. 13

Often the curb and gutter are poured together, but separately from the street paving. Forms similar to those shown in Fig. 14 are used when the curb and gutter are so combined. The form *a* for the inner face of the curb may be sloped, as shown, or straight; or it may be curved as in Fig. 13 (*b*). Specially shaped side rails are made for each design. In the case of a combined curb and gutter, the inner rail *a*, Fig. 14, is held in position at the correct distance from the rail *b* by the division plates, on which it rests, and by horizontals extending over both curb rails and the inside gutter rail.

57. Division Plates.—The forms for combined curbs and gutters are usually connected by steel plates, called division plates. The shape of these plates depends on the particular type of forms for which they are intended. In Fig. 15 is shown the

Heltzel division plate, which is intended for combined curb and gutter forms. The plates fit into holes in the top of the rails, as at *a* in Fig. 10, and thus hold the rails the proper distance apart. The wings at the slots in the plates may be long, as *a* or *b* in Fig. 15, or they may be short, as *k* in Fig. 10, depending on the type of manufacture. In all types, holes *c*, Fig. 15, are

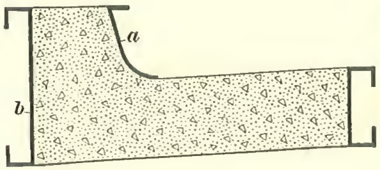


Fig. 14

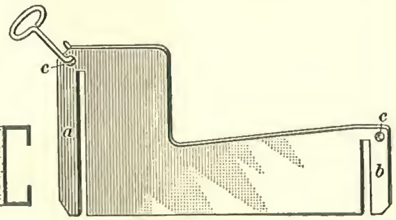


Fig. 15

provided to permit the insertion of hooked handles at both ends of the plate; these handles are used for lowering the plates into place and also for pulling them out.

PLACING CONCRETE AND REINFORCEMENT

58. **Methods of Supporting Reinforcement.**—In the case of a reinforced-concrete pavement, it is very important to have the steel reinforcement in its proper position in the finished slab. The steel must be firmly supported and at the same time there must be no interference with the placing of the concrete. Various methods for placing the reinforcement have been used. In the earlier methods, the steel was set in place first and the concrete was poured around it. Where the rate of progress in paving is comparatively slow, good results may be obtained by supporting the sheets of reinforcement on bent steel bars, called *chairs*, which rest on the subgrade and are left in the concrete. However, where it is desirable to operate a large mixer at its maximum capacity, the placing of chairs tends to delay the work.

In order to eliminate the delay caused by placing chairs, other methods of supporting the sheets of reinforcement were developed. In one method the reinforcement is supported on a sled composed of a series of parallel steel members or runners that are connected at one end by a steel cross-member. The sled is

placed on the finished subgrade with the cross-member attached to the mixer, the reinforcement is laid on the sled, and, as the concrete is deposited, the sled is drawn ahead by the mixer. However, there are several serious objections to the use of a sled, among which are the formation of planes of weakness in the concrete when the runners are withdrawn, and the interference with the placing of the joint accessories and with the depositing of the concrete.

59. The method of constructing concrete pavements that is generally preferred is as follows: The layer of concrete up to the level of the bottom of the steel is deposited before the reinforcement is placed, and the surface of that layer is shaped roughly by means of a templet, or strikeboard. The sheet of reinforcement is then placed on the bed of concrete and is immediately covered with the remainder of the concrete. These operations are carried on continuously so that the concrete of the upper layer is placed before the lower layer begins to set and a good bond between the two layers is thus obtained. Also, the reinforcement is supported firmly and accurately in its correct position and the necessary walking of the laborers on the steel does not tend to bend or distort it to any appreciable extent. Where any one of the previous methods is employed, the steel members must be rather heavy to prevent excessive bending of the sheet under the weight of the workmen.

Marginal bars, dowels, or tie-bars are placed before the concrete is deposited. They are held in position either by chair bars or by vertical steel rods or pins driven partly into the soil. While the concrete is being placed, care should be taken not to disturb the position of such reinforcement.

60. **Prevention of Segregation.**—In order that the concrete in the pavement may be as uniform in texture as possible, it is important that the concrete be deposited on the subgrade as nearly as practicable in the place and shape in which it is to remain. Moving and raking of the concrete should be avoided as much as possible, and care should be taken to remix with a hoe or shovel any portions of the mixture that appear to lack uniformity.

Workmen should never be allowed to walk in the concrete after it has been struck off, as foot marks are usually filled with mortar that is composed largely of laitance and such spots often show up as depressions in the pavement after a few years.

61. Precautions at Construction Joints.—Whenever the interval of time between the placing of successive batches is sufficiently long for the concrete already in place to commence hardening, a square butt joint should be provided. Also, when work is resumed after a stop at noon or at night, it is advisable to use, next to the joint, concrete that is a little deficient in coarse aggregate, because an excess of mortar helps to prevent the formation of a plane of weakness at the joint. This precaution is especially desirable for the first batch mixed in the morning, as some of the mortar from that batch remains as a coating on the interior of the mixing drum and the usual mixture might therefore produce porous concrete.

Even when there is a delay of only 10 or 15 minutes in the supply of concrete, the old and new concrete should be thoroughly sliced together with shovels in order to make sure that no cleavage plane is left. To draw mortar to the edges of the slab next to forms, gutters, or joints and thus assure a face that is free from honeycomb, a straightened hoe or a straight spade with holes cut in it should be worked up and down in the concrete along the slab edges.

62. Depositing Ready-Mixed Concrete.—Wherever possible, even on firm subgrades, it is desirable to place ready-mixed concrete from outside the forms. Many different devices for transferring mixed concrete from the hauling unit to the subgrade have been operated satisfactorily. A good method for use with truck mixers is to discharge the concrete into a mechanical spreader box, which is supported on the side forms, and spans the roadway that is being paved. Such a spreader is best suited for narrow widths of pavement, say up to 10 or 12 feet, but the use of ready-mixed concrete in most cases favors single-lane construction.

Where the mechanical spreader box is not used, a common practice is to discharge the ready-mixed concrete from the truck

into a chute through which the concrete flows directly to the subgrade. For facilitating the discharge of the concrete, most truck mixers have elevating and tilting mechanism and some have a swivel body to enable them to discharge the concrete from outside the forms without backing up to the forms. In constructing part of a road between Wilmington and Dover, in Delaware, central-mixed concrete was placed by means of a bottom-dump bucket that was mounted on the boom of a power shovel from which the dipper was removed.

63. Striking Off Surface Below Steel.—Four general methods for striking off the lower layer of concrete in a reinforced pavement have been used. Where labor is cheap, where a comparatively short length of pavement is to be placed, or where the final finishing of the pavement is not done by machine, a hand-pulled templet may be used for the preliminary strike-off. Another method is to attach to the front of the regular finishing machine an auxiliary plate which is so hinged that, when let down, it strikes off the concrete at the proper height. This method is especially adaptable where the pavement is constructed in lanes and the mixer is outside the forms. In a third method, which can be used only where a paver operates on the subgrade, cables are attached near the ends of the strike-off templet and are run to an auxiliary power shaft on the paver. The fourth arrangement consists in attaching cables to the ends of the strike-off templet and running them toward the mixer, through anchored pulleys, and then back along the edges of the pavement to the framework of the finishing machine; by backing the finishing machine away from the mixer, the strike-off templet is drawn toward the mixer. This method is most successful in paving a two-lane width at one time. The pulleys may be anchored to the subgrade templet, to a projection on the paver, or to pins holding the forms in place.

CONSTRUCTION OF EXPANSION JOINTS

64. Essential Requirements of Transverse Joints.—It is of paramount importance to have transverse expansion joints in pavements exactly perpendicular to the surface of the pavement.

Otherwise, when the concrete expands, one slab will slide on the end of the next one. Also, the filler should be continuous from one edge of the pavement to the other; for, if even a small wedge of concrete spans the joint, spalling or cracking will probably result. In order to insure continuity of the joint, premolded filler should be either in one piece of the proper length or in shorter pieces securely fastened end to end with clips. The metal plate in the longitudinal joint must be stopped 1 to 3 inches from the transverse joint. For the sake of appearance, the transverse joints should run straight across the pavement.

65. Joints With Premolded Filler.—When an expansion joint is made by inserting a prepared filler before the concrete is placed, the filler is held upright by a bulkhead staked in position. Metal bulkheads are better than plank because they are thin and are easily removed without pushing the filler out of line or injuring the concrete. A much used type of metal bulkhead is one that is folded to form an envelope over the top of the filler. If the bottom half of the bulkhead is notched so that it looks like the teeth of a saw, the concrete coming in contact with the filler through these notches will hold the filler in place while the bulkhead is lifted.

Another good type of bulkhead consists of a templet whose bottom is shaped to conform to the surface of the pavement and is provided with a double row of spikes. The templet is set so that it rests on the side forms or curbs and the bottom is at the surface of the pavement. The filler is held in place between the rows of spikes while the concrete is deposited around it. Then the templet is lifted out, and the holes left by the spikes are filled with concrete.

If a plank bulkhead is used, a fairly wide space is left on one side of the filler material when the bulkhead is removed. In order to prevent the filler from being forced out of line by the pressure of the concrete on the other side, the bulkhead should be removed slowly, the operation being started at one edge, and the cavity should be filled with concrete as the bulkhead is lifted. Even with care, it is difficult to obtain a good joint with a plank bulkhead.

When a longitudinal expansion joint is placed next to a curb or to a finished slab in lane construction, the filler should be held tightly against the curb or finished slab while the concrete is being placed, so that small pebbles or pieces of concrete will not get in between the filler and the curb or slab and thus form an opening through which water will reach the subgrade.

66. Some specifications require that the top of the premolded filler in expansion joints be flush with the finished pavement surface and that the strike-off templet be moved away from the joint. However, it is comparatively difficult to spread the concrete when the strikeboard is moved backwards from a joint. On the other hand, when the strikeboard is pulled up to the joint, it either presses the top of the filler forwards and forms a leaning joint or else piles concrete behind the joint material and makes a noticeable hump. Therefore, the top of the joint material is often set about $\frac{1}{2}$ inch below the surface of the pavement, the surface is finished as if the joint were not present, and, after other finishing operations have been completed, the concrete over the joint is removed and the edges are rounded. Concrete should not be left over the filler, as expansion of the slab would break out this concrete and cause spalling over a comparatively large area.

67. Poured Joints.—A poured expansion joint is constructed by placing in the slab a temporary bulkhead which when removed leaves a crevice for holding the poured filler. The bulkhead may consist of a slightly wedge-shaped board around which are several loops of wire that facilitate its removal. In order to prevent the concrete from adhering to the board and binding it in position, the board may be set between galvanized iron plates. After the hardening of the slab has progressed sufficiently, but not too far, the board is pulled out, freeing the galvanized iron plates and allowing their removal without injury to the concrete. Several patented collapsible bulkheads are also in use.

The crevice left by the bulkhead is cleaned with a pointed hook, and hot bitumen is poured into it. Tar or asphalt filling should be hot enough to be quite liquid so that it will fill the space and

make a watertight joint, and should be of a quality that will not crack and chip out during cold weather nor run during hot weather.

STRIKING OFF AND FINISHING OF SURFACE

68. Machine and Hand Work.—Finishing machines for concrete pavements have been developed to such a high degree of perfection that a machine-finished surface produced by an experienced operator has much better riding qualities than the best hand-finished surface ever constructed. Moreover, the rate of progress is much more rapid with the machine and a concrete of much drier consistency can be used. Machine finishing is now required on all state highway work, and it is only on some city streets, where there are frequent intersections and variations in width, that hand finishing is still found to be advantageous.

69. Finishing Machines.—A typical finishing machine for concrete pavements is shown in Fig. 16. It consists of a rigid frame mounted on wheels *a* that run on the top flanges of the side forms *b*. The machine in the illustration is provided with a single strike-off screed *c* at the front and a tamper *d* just behind the front pair of wheels. However, machines may be equipped in any one of the following four ways: (1) with a single screed in front; (2) with a double or tandem screed, one in front and the other some distance behind the first; (3) with one screed and a tamper; (4) with two screeds and a tamper between them. Machines are available for any width of pavement from 8 to 30 feet. Some types of machines have six wheels instead of four.

The screeds have wide bottom surfaces, so that there is a large area of contact between them and the top of the pavement. As the machine moves along the pavement, the screeds move from side to side for a few inches and thus knead the concrete. The tamper is a wooden plank with a steel shoe on the bottom. It is not a surfacing member, but helps to compact the concrete and facilitates the finishing where a harsh, dry mix is used. It is separately controlled and can be operated independently of the screeds.

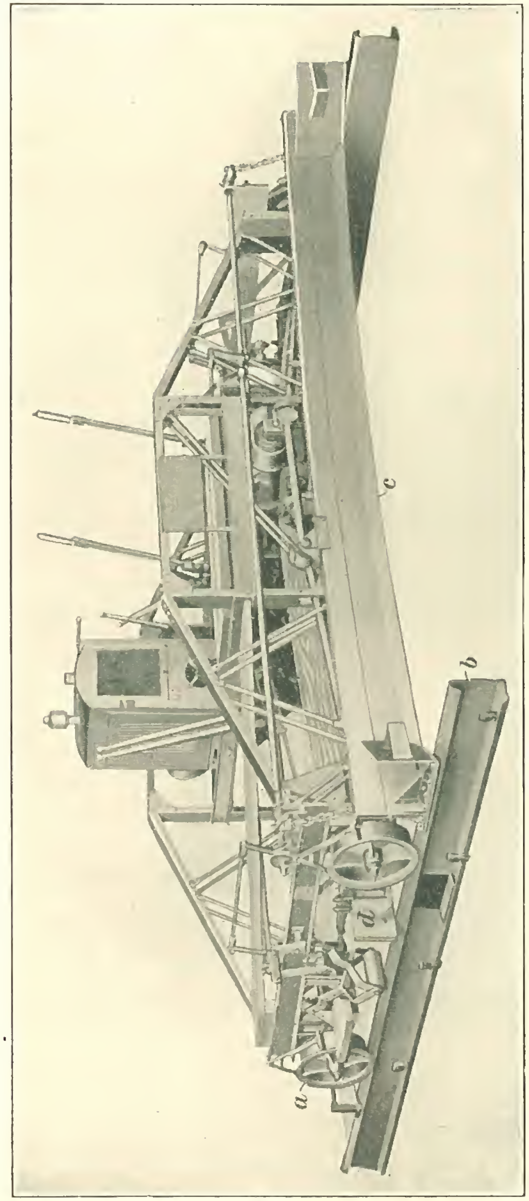


Fig. 16

70. Finishing Operations.—The operations in finishing a pavement by machine are usually as follows: The machine is first run forwards over the concrete, which has been roughly spread upon the subgrade to a height an inch or two above the desired finished surface. As the machine advances, the screed in front accumulates the excess concrete in a pile, and at the same time the weight of this pile and the pressure exerted by the screed compact the concrete in the slab just ahead of the screed. The weight of the screed is sufficient to prevent it from being lifted by the resistance of the concrete and the pressure that is transmitted back through the concrete, but this pressure forces a little concrete to pass under the screed so that the surface behind the screed will be slightly too high. When there is a second screed on the machine, as is commonly the case, it gathers up and spreads the excess material, which is mainly mortar, and shapes the surface to the correct height and crown. The height of the pile of concrete carried ahead of the front screed should not exceed two-thirds of the height of the screed. Also, it is advisable that the front screed have a crown about $\frac{3}{16}$ inch in excess of the required crown of the pavement, in order that the second screed may produce a true surface.

Any defective spots that are left after the first passage of the machine may be readily eliminated by spreading a little more concrete over those spots and running the machine over the surface a second time. Ordinarily, two passages of the machine will be sufficient, but if the concrete is unusually stiff, the aggregate is very coarse, or there is a deficiency of mortar, a third trip of the machine may be necessary.

Where one screed and the tamper are used, the usual method of procedure is first to run the machine over the surface with the screed ahead of the tamper, then to run the machine backwards over the pavement so as to reverse the order of the tamping and screeding operations, and finally to make a third trip in which the screed alone is used.

The pavement is usually given a final finish by means of a belt float. Such a float may be carried at the rear of the finishing machine, and driven back and forth across the pavement by mechanism on the machine.

71. Finishing by Machine Under Special Conditions. When an old pavement is to be widened or a wide pavement is to be constructed in lanes, a side form can be used for only one edge of the new slab. In order that the finishing machine may be supported on the old concrete instead of on a form, the flanged wheels on one side may be replaced with wheels having flat treads. In this case, the wheels on the other side of the machine, which run on forms, should have double flanges, as the machine must be guided by the forms alone.

Where the pavement is widened on a curve and the maximum widening does not exceed 2 feet, a special attachment may be fitted to either side of the narrower finishing machines so that the machine can run on the regular side forms, which are set for the full width of slab. This attachment is provided with a long axle on which the wheel can move sidewise to follow the form on the widened side of the road. Of course, when this fixture is used, a wider screed replaces the standard one.

On a curve for which the widening exceeds 2 feet, it is necessary to set false forms for the normal width of the pavement and to have the machine run on these forms. The standard screed on the machine may be replaced by a special one that is long enough to cover the entire width of the pavement. After the machine has gone over the pavement, the false form is removed and the space it occupied is filled with concrete. This portion of the pavement is finished by hand. Another method is to finish the normal width of the pavement by machine and to finish the widened portion by hand, care being taken to secure a good bond between the main body of the slab and the widened portion.

72. The finishing machine may be used also where the surface of the concrete is to be below the bottom of the standard screed. In such a case, an extra screed or strikeboard may be attached to the machine at the proper level. For instance, the concrete below the reinforcement may be struck off by a templet that is hinged to the front of the machine and can be either lowered into position or else raised out of position to permit the finishing of the pavement surface. Similarly, a concrete base course below the forms may be finished by a machine operating

on the forms, or a pavement may be finished by a machine operated on curbs already in place.

When a concrete pavement with integral curbs is finished by machine, the tops of the forms are set at the level of the slab proper, the entire width of pavement is finished to that level, and the curb forms are then put in place and the curb is molded by hand immediately behind the machine. Where the curb is integral with a concrete base course, the forms are set to the level of the top of the curb and the screed on the finishing machine is set to finish the slab at the level of the top of base and for a width slightly greater than the distance between the inside faces of the curbs; the forms for the inner faces of the curbs are then set in place and the curbs are constructed. The belt float is not used on a base course with integral curbs.

A good method to be followed at the intersection of two streets, such as those shown in Fig. 2, both of which are being finished by machine, is as follows: The concreting on the street first paved, say street *A,* is stopped at the expansion joints along the edges of the other street, or the joints *eabe,* but the forms are continued through the intersection temporarily in order to carry the machine across the unpaved middle strip *abba.* The forms that lie within the area to be paved, or along the dotted lines *af* and *bf,* are removed immediately after the machine has passed, and the concrete in the portions *eaf* and *ebf* that are not reached by the machine is struck off and finished by hand, precautions being taken to insure a good bond with the main body of the pavement. The middle strip *abba* is paved with the second street *B.* The machine can then ride across the intersection on the edges of the finished slab for the street *A* and on temporary forms laid along the dotted lines *ag* and *bg.*

73. Hand Finishing.—Even on city streets, finishing machines can be used for a large part of the area. However, on irregular portions of intersections and for other special work, hand finishing is necessary. The first operation in hand work is to strike off the concrete with a templet that will leave the surface $\frac{1}{4}$ or $\frac{1}{2}$ inch high. This templet should weigh at least 15 pounds per foot of length and its bottom should be faced with

metal. The next operation is to tamp the pavement with a broad, heavy templet that is operated by two men. Its lower surface should be shaped exactly to the required cross-section, so that when its ends rest on the side forms the surface of the pavement will be correct.

After the concrete has been tamped to shape, any ridges at right angles to the direction of traffic are eliminated by means of a longitudinal float. This is a plank from 12 to 20 feet long stiffened with a rib along the top and provided with plow handles

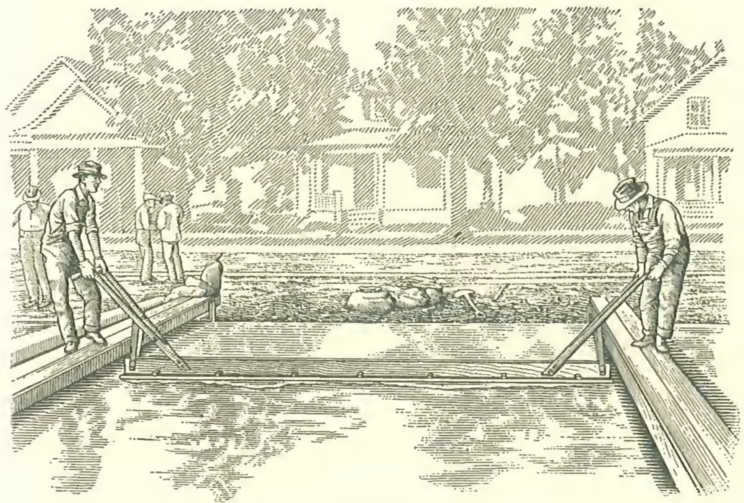


Fig. 17

at the ends. As shown in Fig. 17, it is operated parallel to the center line by two men from two bridges spanning the pavement. It is worked from one side of the pavement to the other with a sawing motion and then pulled back again with a wiping motion.

The final finishing operation consists in smoothing out by several passages of a belt float the small irregularities that are left by the longitudinal float. The belt is about 2 feet longer than the width of the pavement and is pulled backwards and forwards across the concrete surface with a sawing motion. In the first passage of the belt, the strokes are at least 12 inches

long and the advance at each stroke is small. On each subsequent passage, the strokes are shorter and the advance per stroke is greater. After the pavement has lost its so-called water glaze or sheen, the surface is given a final belting. In this trip, the strokes are only about 4 inches long and the rate of advance is quite rapid.

74. Checking and Correcting Surface.—It is generally required that variations in the surface of a concrete pavement, as indicated by a 10-foot straightedge, should not exceed $\frac{1}{8}$ inch. As soon as the concrete has begun to harden and just before it is given the final belting, every part of the surface should be checked with a straightedge and any excessive irregularities should be corrected at once.

If the concrete is allowed to harden before the surface is checked and corrected, much greater difficulty is encountered in removing high spots. Such spots may be rubbed by hand with a carborundum stone, or a special grinding machine may be used. Some specifications require that high spots in hardened concrete be removed by bush-hammering. These treatments expose the coarse aggregate and detract from the appearance of the pavement, but do not weaken the slab. However, the contractor is severely penalized for not being careful to have the surface right before the concrete hardens.

75. Finishing Integral Curb.—In the case of a pavement with integral curbs, the pavement proper is finished for a sufficient distance ahead so as not to interfere with the placing of a length of curb form, and then the forms for the curbs are set in position and filled with concrete. This concrete should be well spaded along the form faces to insure a dense, smooth surface, and the spade should be worked into the concrete deep enough to make certain that the curb will be well bonded to the pavement. The excess concrete in the curb form is struck off and the work is allowed to remain undisturbed until the concrete has hardened sufficiently, when the face form is removed and the finishing completed. Joints in the curb are made where joints in the pavement slab occur, thus making pavement joints continuous through the curb. It is important that the joint in

the curb between adjacent sections be at least as wide as the joint in the pavement. Also, the separation should be made complete from back to front and from bottom to top of curb. Integral curb should be finished each day to the point where pavement work is stopped, because if part of it is left to be placed on the following day it is certain that there will be a poor bond, and cracking will result later from temperature changes and frost action.

When there is a little rise and fall in the gutter, drainage can be improved by steel-troweling the pavement surface for a distance of about 18 inches out from the curb line.

76. Shaping Intersections.—Wherever possible, the concrete at street or road intersections should be struck off with a templet. In most cases, templets can be made to extend from the center line of each roadway to the edges of the normal width, but considerable shaping of the slab outside the limits of the templets is often required. Where a templet cannot be used, numerous stakes should be carefully set to grade by means of a leveling instrument. Between these stakes, the surface can be shaped by shovels and floats or wooden lutes, which resemble toothless garden rakes; a rake should never be employed. Metal stakes with a lug about 1 inch below the top should be used, the lug being set to the elevation of the slab. The projections are then visible, and it is impossible to leave stakes in the pavement after the surface is finished, as might be the case if their tops marked the elevation of the surface. It is advantageous to construct in advance the portions of the intersection outside the edges of the roadway along which the paving is being done, so that the workmen can walk on these completed parts while finishing the rest of the slab.

77. Streets With Variable Gutter Heights.—In order to take care of the drainage, street gutters must slope longitudinally. However, it is sometimes desirable to have the top of the curb level for an entire block and to obtain the slope of the gutter by varying the height of the exposed face of the curb. In such a case, the roadway surface cannot be struck off with a templet resting on the curbs. Sometimes, it may be possible to set a

form along the center line of the street and a guide rail near the curb at the elevation of the finished slab, and to rest on them a templet for half the width of pavement. If no templet is used, grade stakes should be set about 10 feet apart in both directions. Shovels and floats can then be used for shaping the surface between stakes. A long-handled float, such as illustrated in Fig. 18, is advantageous for this work, and a longitudinal float aids in gettting a smooth-riding surface.

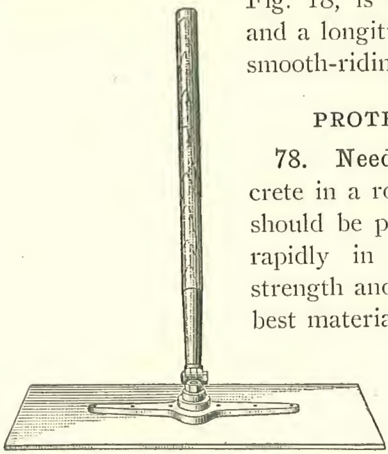


Fig. 18

PROTECTION AND CURING

78. **Need for Curing.**—After the concrete in a road or street has been laid, it should be protected from drying out too rapidly in order to secure maximum strength and best wearing qualities. The best materials and workmanship will not produce a satisfactory pavement if the concrete is allowed to dry out rapidly in hot weather by exposure to hot winds, if it is exposed to low temperatures and is allowed to freeze before it has hardened, or if the pavement is opened to traffic too soon after the last concrete is placed. It is of paramount importance to protect the concrete against premature drying in the first few days and especially during the first few hours.

79. **Methods of Curing.**—Several methods of curing concrete pavement slabs are in common use and have given satisfactory results. The application of water in some manner is still the method most often used. Sometimes, calcium chloride is used either as an admixture in the concrete or as a surface covering on the finished slab, and in other cases the finished surface is covered with sodium silicate, a bituminous coating, or reinforced waterproof paper.

80. **Water Curing.**—When a pavement is to be cured by means of water, the first step usually is to spread wet burlap on

the slab as soon as the surface has hardened enough not to be marred by it. On the following day, or sooner if the concrete has hardened sufficiently to permit applying a layer of protective material, the burlap may be removed and the concrete protected by cheaper material. In highway construction the most commonly used method is to place on top of the concrete slab a covering of 2 inches of earth, sand, or wood shavings, or of 5 or 6 inches of hay or straw, and to keep the covering moist by sufficient sprinkling. This covering should be left on for 7 to 14 days. Whenever there is a surplus of material from the cuts, it is desirable to leave sufficient earth at the roadside to be used later for covering the pavement surface in the process of curing. This will save the expense of rehauling the earth required for the protective covering and, if necessary, the material can be hauled away more economically after the road has been opened to traffic.

On city streets, it is customary to cure the pavement by continuous sprinkling after the removal of the burlap, rather than by applying a wet covering. Earth is objectionable as a covering in built-up districts because mud is likely to be spread onto adjacent sidewalks and streets; materials like straw, shavings, and hay are not often used in cities as they are easily blown over the lawns. Where sufficient water pressure is available, sprinkling may be economically accomplished by installing a system of nozzles which throw a spray over the concrete surface.

Where water is plentiful and the grade of the road is not excessive, the ponding method of curing a concrete highway pavement may be used with success and at a less cost than that required to apply and sprinkle an earth, straw, or similar cover. In this method, small dikes and dams, as shown in Fig. 19, are made by banking clay or earth about 10 inches wide and high, so that the water will be retained in small ponds on the pavement surface. The pavement is then flooded until the water stands at least 2 inches deep over the center of the pavement. If there is curbing, only cross-dikes are required, and these should be placed about 15 feet apart and preferably over expansion joints to prevent water from entering the subgrade at these points. The ponding method is only suited to pavement surfaces where the grade is flat or under 3 per cent., because any greater grade

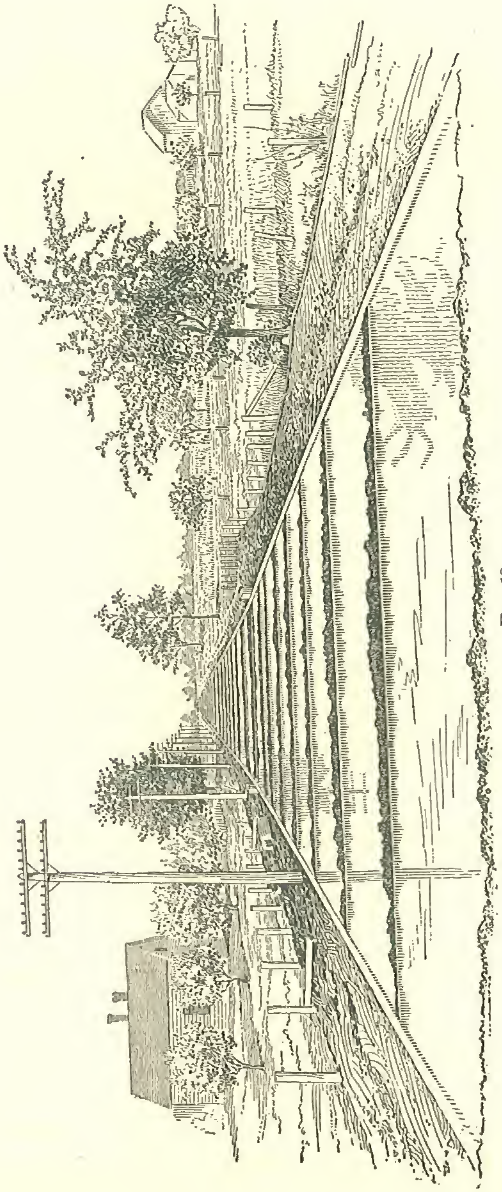


FIG. 19

than this requires dikes so high as to make the method uneconomical.

81. **Curing With Calcium Chloride.**—The function of calcium chloride in the curing of concrete is to absorb moisture from the air and thus keep the concrete moist. When calcium chloride is used as an admixture, it is fed into the mixing drum in the form of a solution in water, 4 pounds of flake calcium chloride being contained in each gallon of solution. Under usual conditions, specifications generally call for 2 pounds of calcium chloride per sack of cement. This quantity is provided by adding 2 quarts of the standard solution to the mixture for each sack of cement. The volume of the solution thus added should be considered as an equal volume of mixing water. After the pavement is finished, the only curing treatment consists in covering the slab with wet burlap for about 24 hours.

If calcium chloride is to be applied as a surface covering, the finished pavement is first covered with wet burlap, as in the water-curing methods. However, the burlap should be removed and flake calcium chloride spread as soon as practicable after the concrete has taken its final set, and not later than 10 A. M. on the day following the placing of the concrete. The calcium chloride is spread uniformly at the rate of 2 to 3 pounds per square yard of pavement, a squeegee or a mechanical spreading device being used.

82. **Curing With Sodium Silicate.**—Sodium silicate, which is commonly known as *water glass,* is a syrupy liquid which is applied to the surface of the concrete in order to provide a thin varnish-like film and thus prevent the rapid evaporation of the water in the concrete. When sodium silicate is to be used, the freshly finished concrete is covered with damp burlap until the following morning. As soon as the burlap is removed, the sodium silicate is applied to the pavement in the form of a solution in water to facilitate spreading the material over the entire surface. About 1 pound of sodium silicate per square yard of surface is used, and the proportions of the solution by volume are generally 3 parts of sodium silicate to 1 part of water.

83. Curing With Bituminous Paint or Waterproof Paper. As in the case of sodium silicate, the purpose of applying a bituminous paint to the surface of a concrete pavement is to prevent rapid evaporation of the water contained in the concrete. However, such paints are usually sprayed onto the pavement immediately after the final finishing operation. Because of their black color, bituminous coatings tend to absorb heat from the sun's rays. Therefore, abnormal expansion and contraction of the concrete is apt to take place and, in order to prevent excessive cracking of the pavement, frequent joints should be provided in the slab. The usual requirement for slabs cured with bituminous materials is the construction of transverse joints of either the expansion or the contraction type at intervals not exceeding 40 feet.

Waterproof paper is intended to act in the same manner as a bituminous paint. The paper is generally strengthened by the inclusion of rope fibers. It is laid on the pavement as soon as possible after the concrete has been finished and is left in place until the end of the curing period.

84. Protection in Cold Weather.—During cold weather, the methods ordinarily used for curing and protecting concrete pavements are modified considerably. The temperature at night is likely to drop low and, if the pavement is covered with earth and sprinkled, warmth that might be obtained from the sun during the daytime to harden the concrete will largely go to dry out and heat the earth covering. Therefore, in cold weather pavements should not be covered with earth but should merely be sprinkled sufficiently to keep the surface moist or should be otherwise protected from rapid evaporation in the daytime.

Concrete pavement construction should never be carried on at a season of the year when freezing may be expected; the work should be suspended until favorable weather conditions prevail. If for any reason it is necessary to finish a short section of slab so that the work may be discontinued at an advantageous point, then aggregates and mixing water should be heated. Also, less mixing water should preferably be used. Concrete should never be laid on a frozen subgrade.

85. Opening Pavement to Traffic.—It is desirable to open the pavement to traffic as soon as possible. During warm weather a concrete pavement may safely be opened to traffic in about 14 days. However, in order to avoid delay in opening the pavement after it has become sufficiently strong, the practice in many states is to test specimen beams of the concrete that is placed in the pavement. These specimens are made each day and are cured alongside the pavement in the same way as the pavement slab. They are tested at the age of 7 or 8 days and at intervals, as necessary, until the concrete has developed a modulus of rupture of at least 450 pounds per square inch; where 5-ton trucks are expected to use the pavement as soon as it is opened, a modulus of rupture of 500 pounds is generally required. If the pavement was cured by means of a covering of damp earth, straw, or similar material, the covering is removed when the specified strength is attained, and the pavement is air-cured for a day or two and then opened to traffic. Since concrete is stronger when dry than when wet, every pavement should be allowed to dry out before it is opened to traffic. During cold weather, concrete will harden slowly and the curing period must be extended. Only experience or tests can determine how much. The long period of curing generally required can be materially shortened by employing a concrete of high early strength.

MAINTENANCE AND REPAIRS

86. Provisions for Maintenance.—The best possible provision for maintenance of a concrete road is to use good materials and the best methods of construction, so that repairs will be infrequent. The defects in a concrete road can almost always be traced to some fault in the materials or in preparing or placing the concrete, or to neglect of some important features in preparing the subgrade.

Next in importance to employing good materials and insuring thorough workmanship is taking care that all imperfections in the road should receive attention as soon as they are discovered. If this is not done, small breaks will become large holes, and expensive repairs will be necessary.

The repairs that are likely to be necessary to concrete pavements will fall mostly into three general classes: (1) The replacement of the pavement where it has been cut through to lay or repair underground pipes or other municipal work; (2) the repair of depressions or chuck holes caused either by original faulty construction or by the normal effects of wear; (3) repairs along expansion joints or self-formed cracks in the pavement. Repair patches that are properly made should prove as durable as the original pavement, and should not be noticeable after being exposed to traffic for a short time.

87. **Repairing Cuts Through Pavement.**—Where a cut has been made through the entire depth of the pavement and the foundation bed has been excavated, as when a utility pipe is

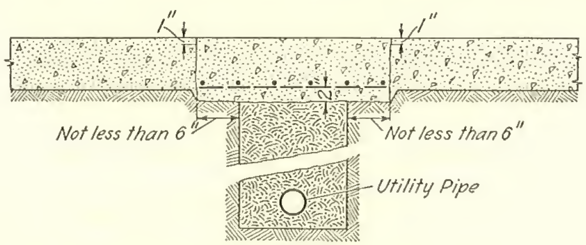


Fig. 20

laid, the back-filling of the trench must be given careful consideration. The restored pavement may reasonably be expected to serve its original purpose of transmitting and distributing its loads to the foundation bed, but not to perform the function of a bridge spanning a sunken trench several feet wide. Where a trench of considerable depth in soft or crumbling earth has remained open for some time, its sides are likely to have caved in, leaving the pavement at the edge of the trench overhanging the caved portion. Therefore, the cut in the slab should extend at least 6 inches beyond each edge of the trench, as shown in Fig. 20. Where the subgrade thus exposed is of proper stability, it should not be adjusted in any way. Foreign materials are added to the subgrade only where it is necessary to remove unstable material for a depth exceeding 6 inches. The back-filling material that is placed in the excavated trench should be

deposited in layers about 4 inches thick and must be thoroughly compacted either by flooding with water or by mechanical tamping.

An exposed edge of the original slab against which the new concrete is to abut should not be made vertical for the entire depth of the slab; but, as shown in Fig. 20, it should be plumbed for a depth of not more than 1 inch at the top in order to provide a firm shoulder for the new patch. In the lower part of the slab, a rough, uneven edge materially improves the bond between the old and the new concrete. In case there are spalled or scaled areas of the old surface adjacent to the cut, the concrete at such places should be removed for the entire depth of slab. If these areas are left and later plastered with mortar, the repairs will chip out quickly.

Just before the new concrete is placed, the edges of the original slab should be thoroughly washed with water and scrubbed with wire brushes and then wetted down and painted with mortar composed of equal parts of cement and sand. The concrete must be placed immediately after the painting has been done.

88. The new concrete over a service cut should be as nearly as practicable of the same composition and quality as the old. However, in order to avoid the long curing period allowed in the original construction, not more than 4 gallons of water per sack of cement should be used and concrete without admixtures should be mixed for $2\frac{1}{2}$ to 5 minutes in a machine mixer. As this mixture is too dry to be readily workable, it should be placed in the pavement in layers 2 inches thick and each layer should be thoroughly tamped. When the patch is first placed, the surface should be slightly above the old grade. Just before the concrete has taken its initial set, or after it has shrunk as much as possible without entirely losing its plasticity, it should be tamped thoroughly, planed to the proper grade, and finished. Unless practically all shrinkage has taken place before this final working, the bond between the old and the new concrete will be weak. The concrete in a patch of this kind need ordinarily be cured for only 18 to 24 hours, and even under especially adverse conditions 72 hours should be sufficient. Where an

accelerating admixture, such as calcium chloride, is used in the concrete, the mixing period should not exceed $2\frac{1}{2}$ minutes, as otherwise the initial set may occur prematurely.

Whether or not the original pavement is reinforced with steel, a mat of $\frac{3}{8}$-inch round bars running in both directions and spaced not more than 12 inches on centers should be placed about 2 inches above the bottom of the concrete in the patch, as shown in Fig. 20. In the case of a reinforced pavement, the old reinforcement in the area to be repaired should not be cut out but should be temporarily bent out of the way and afterwards returned as nearly as possible to its original position. Also, the patch should be provided with new reinforcement corresponding in size, spacing, and position to that in the original slab, and the new reinforcement should be tied in with the old steel.

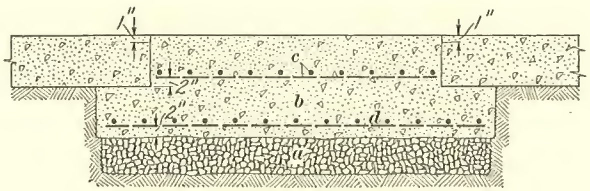


Fig. 21

89. Repairing Pavement Failures.—Where a pavement failure is the result of insufficient compaction of the subgrade, the cause of failure must be remedied before the pavement is repaired. In order to allow for the possibility of the subgrade instability extending beyond the restored section of pavement, the subgrade material adjacent to the patch, as well as that under it, should be removed to the required depth. Where the required depth of excavation exceeds 6 inches, as indicated in Fig. 21, the space up to a level about 6 inches below the bottom of the original pavement is refilled with a thoroughly compacted subbase *a* of broken stone or similar granular material, and the remainder of the space is filled with concrete *b* which extends under the edges of the old pavement. This new concrete should be reinforced with a mat of steel *c* placed at a level that is about 2 inches above the bottom of the original pavement slab, and

preferably with a second mat *d* located 2 inches above the bottom of the concrete patch.

If the pavement failure is caused by unsatisfactory drainage of the subgrade, lateral drains should be provided. A simple inspection will be sufficient to determine the necessity of such drains.

90. Where a depression, or so-called chuck hole, 2 inches or more in depth has formed in a concrete pavement as the result of defects in the wearing surface, the hole should be cleaned of all debris, dirt, and loose concrete. The precautions to be taken in preparing the exposed edges of the original slab and in mixing, placing, finishing, and curing the new concrete are the same as described under repairing cuts for service pipes.

A depression between 1 inch and 2 inches in depth should first be thoroughly cleaned and dried. Then the exposed surfaces should be painted with hot tar or rapid-curing asphalt, and the cavity should be filled with pebbles and sand so graded that a minimum of voids is secured. After this material has been compacted by tamping or rolling, enough rapid-curing asphalt or hot tar should be poured on to fill the voids and leave a slight excess on the surface. Dry sand is then spread over the patch, and the surface is thoroughly tamped or is left to be ironed down by traffic.

Imperfections up to 1 inch in depth are repaired in the same manner as expansion joints.

91. Repairing Expansion Joints.—Cracks and expansion joints that are spalled are swept clean with wire brooms, and hot tar at 225° F. is poured in to fill the crack and allow a slight excess on the surface. The tar should be allowed to stand for a brief time, say 1 minute, to prevent bubbles, and clean coarse sand should then be spread on. The traffic will iron out the excess filler, but better appearance will be obtained if it is scraped off with a hot shovel.

When the expansion joints have disintegrated so that deep holes have formed, the method for repairing holes more than 2 inches deep should be used.

92. **Restoring or Resurfacing Settled Pavement.**—Depressions in a concrete pavement that were caused by settlement may sometimes be repaired either by raising the slab to its original position and filling the space between the slab and the old subgrade or by resurfacing the low portion of the slab. The old method of raising a slab consisted in cutting a trench in the subgrade large enough to permit the installation and operation of jacks, lifting the slab a little above the desired level, and tamping earth into the space beneath the slab. However, this method proved to be unsatisfactory and was often expensive. Better results have been obtained by the use of machines, called *mud jacks,* which pump enough mud under the sunken slabs to raise them to the proper elevations.

93. Where it is desired to level up a concrete pavement by applying additional surfacing material, a layer of portland-cement concrete should be used for depths exceeding about 3 inches, and either hot or cold bituminous concrete for shallower depths. However, asphalt patches in a concrete street usually wear more rapidly than the adjacent concrete and detract from the appearance of the street. They should, therefore, be avoided whenever possible.

In order to obtain as good a bond as possible between the old surface and a cement-concrete patch, the top of the old slab should be roughened and the edges of the patch should be made vertical. Just before the new material is placed, the roughened surface should be thoroughly cleaned with brooms and water and then covered with a thin paste of neat cement. The new concrete should be prepared, placed, and treated as described for a patch over a cut for a service pipe.

In patching with a hot bituminous mixture, the depression is first filled with dry stones ranging in size from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches. Then, hot asphaltic cement with a penetration somewhat less than that ordinarily used for bituminous concrete in the same locality is poured over the stones, hot stone screenings are scattered over the patch, and asphalt is poured over the screenings. The patch is brought exactly to the proper elevation by means of a straightedge resting on the unpatched portion of the slab, and the new surface is smoothed with a hot iron.

If cold bituminous material is to be used for patching, the mixture is prepared in advance and tamped into the depression without being heated.

94. **Salvaging Old Concrete Pavements.**—An old concrete pavement that is no longer suitable for its original purpose may often be utilized as a base for a new wearing surface. The resurfacing course may be of cement concrete, bituminous concrete, brick, stone blocks, or other suitable construction. Where the resurfacing layer is to be of cement concrete, that layer should be at least 4 inches thick. It should be either bonded as completely as possible to the old pavement or entirely separate. If the two courses are bonded, greater flexural strength is obtained, but there is more likelihood that the cracking in the old slab will be transmitted to the new layer.

BASE COURSES FOR PAVEMENTS

FLEXIBLE BASES

95. **Gravel Bases.**—A gravel base can support a pavement satisfactorily only where the subgrade is constantly firm and good drainage is provided. Subgrade materials on which gravel bases may be used are sands, sandy gravels, good topsoils, good sand-clays, silts that are well above the ground-water level, and homogeneous clays that are high above the ground-water level and have good internal drainage.

By compacting the particles of gravel, the load-distributing power of the base is increased. Also, since the base transmits to the subgrade heavier loads than could be carried without a base, the gravel causes greater compaction of the subgrade and increases the supporting power of the soil itself. Where stage construction is employed, the gravel of the base may be forced down into the subgrade soil, and thus the character of the soil may be improved to the depth of penetration.

96. **Waterbound-Macadam Bases.**—Bases of bonded macadams, of which waterbound macadam is a typical example,

are in many respects quite similar to gravel bases. Firm and non-elastic subgrade support must be provided and maintained if the construction of a macadam base of economical thickness is to be successful.

Macadam bases can generally be used to advantage on coarse sands, sandy gravels, loams, and good sand-clays and topsoils. On firm silts, in which there is considerable capillarity and therefore likelihood of frost heave, adequate drainage is essential and a thick base should be provided. In case the soil cannot be well drained, a macadam base is not suitable. A subgrade of silt may be improved by mixing sand into it or applying oil to its surface.

Homogeneous impermeable clays and well-drained permeable clays require thick macadam bases, and subgrade treatment consisting of a sand blanket or an oil coating is recommended. If a permeable clay cannot be well drained, the success of a macadam base is doubtful. As a general rule, it is not advisable to construct macadam bases on very fine sands or on elastic silts, clays, peats, and mucks, unless the elasticity has been worked out of the soil by traffic action and the action of the elements, and thorough drainage is provided to keep the ground-water level low. Even under favorable conditions, a thick course of macadam is required.

97. **Bituminous Bases.**—In general, bituminous-macadam bases are similar to waterbound-macadam courses in the relation of the base to the subgrade. Where a high degree of subgrade support is maintained, bituminous-macadam bases have generally given good results. Except on subgrades having high supporting strength, such bases are usually placed on subbases of granular material like bank-run gravel, crushed stone, or crushed slag. Bituminous-concrete bases, or so-called black bases, have given excellent service over a long period of years wherever good subgrade support is provided.

RIGID BASES

98. **General Remarks.**—A rigid base for a pavement does not need firm subgrade support, as such a base transfers the loads from the pavement to the subgrade by its beam strength. Nevertheless, it is important that the subgrade support be fairly uniform. Otherwise, at each point where the compactness of the supporting soil changes, the base is subjected by traffic to repeated pounding, and a series of blows in rapid succession causes failure of the base much more quickly than would a heavier load coming on the base without shock.

The vast majority of bases for city streets are now being built of portland-cement concrete. Bases of this type are also widely used for highway pavements, especially where the subgrade conditions are unfavorable. There is a general trend toward the more widespread use of steel reinforcement in concrete bases for both highways and streets.

New foundations are seldom constructed of brick or stone blocks, but old pavements of this type are sometimes used as bases for new bituminous-concrete or cement-concrete pavements.

99. **Requirements for Concrete Bases.**—The results of investigations show that the strength of a pavement made up of a concrete base and a wearing course of bituminous concrete or brick with bituminous-filled joints is dependent almost entirely on the strength of the base. Therefore, the thickness of a concrete base is usually determined by applying the formula of Art. 9, as in the case of an all-concrete pavement. However, the wearing course is of definite value in reducing the effects of loads and of temperature and moisture changes on the concrete base.

Because of the protection afforded by the wearing course, it has been common practice to use for the base a concrete of comparatively low strength. However, as shown by experience, although such concrete may be strong enough to resist the effects of loads on the base, it is seldom sufficiently durable. In order to insure satisfactory durability of the base, it is essential to keep

water from entering the concrete from the subgrade. Hence, the concrete should be made as dense as practicable by using a fairly low water-cement ratio. Such concrete will have a relatively high strength.

100. Reinforcement and Joints in Concrete Bases.—Steel reinforcement and longitudinal and transverse joints help to prevent irregular cracking in a concrete base in the same way as in an all-concrete pavement, and there is a general trend toward their more widespread use in bases. When reinforcement is provided, it is distributed in the manner described for a concrete pavement.

The use of expansion joints in bases has been retarded by the lack of a really satisfactory type of joint. There are several objections to a joint filled with plastic material, such as asphalt. When the slabs expand, the material is squeezed out of the joint and upwards, and unevenness in the wearing course results. Later when the slabs contract and the joint opens, dirt and other foreign materials enter, and the efficiency of the joint is thus reduced. The loss of filler on expansion and the entrance of dirt and foreign material on contraction also occur in the case of expansion joints in all-concrete pavements, but such joints are exposed and repairs can be made more readily. The development of rubber and cork joint-fillers and the use of a metal joint in which an air space is provided seem to have overcome the difficulties encountered with plastic materials.

It is generally considered advisable to space expansion joints in a base at rather short intervals. The greatest movement of the base will then be small, and the cracks that will form in the wearing course because of this movement will not require maintenance. Some engineers maintain that where reinforcement is provided the use of contraction joints at intervals of about 20 feet without expansion joints is satisfactory, the reason being that for a normal range of temperature the shrinkage of the concrete during setting is sufficient to provide for expansion caused by rise in temperature. In constructing concrete bases for brick pavements, good results have been obtained in several cases by providing 2-inch open expansion joints at intervals of 240 feet

and contraction joints of the dummy type at 40-foot intervals. The expansion joints were sealed at the bottom with 1 inch of bituminous material and covered with a strip of light-gage galvanized sheet metal, which was sealed in place by a strip of burlap and bituminous material. The grooves in the contraction joints were filled with bituminous material and each joint was covered with a strip of burlap.

Longitudinal contraction joints similar to those in all-concrete pavements are also effective in controlling longitudinal cracking in concrete bases.

101. Finishing Concrete Base.—The surface of a concrete base is usually made parallel to the finished surface of the pavement; that is, the crown is introduced in the base and the thickness of the wearing course is made uniform for its entire width. Concrete bases should be finished by machine rather than by hand. However, the surface of a base course need not be so smooth as that of a concrete pavement. In fact, the surface of a concrete base for a bituminous-concrete wearing course should be uniformly rough in order to prevent longitudinal creeping of the top course on the base.

SUBBASES

102. Subbases of various granular materials have been employed under pavement bases in order to improve pavement service in one or more of the following ways: (1) by draining the subgrade; (2) by reducing the extent of heaving due to frost action; (3) by replacing an equal thickness of undesirable soil; (4) by increasing the area of soil over which a load on the pavement is distributed; (5) by decreasing the amount of cracking in the pavement.

A subbase that is properly designed and constructed is undoubtedly of great value under a flexible base course, but data on the benefits of subbases under concrete bases are inconsistent. A porous subbase may assist in draining the subgrade where side drainage is not blocked; otherwise, the porous material may serve as a reservoir for water. Subbases would have to be excessively deep to eliminate frost action entirely, but they may

reduce the extent of heaving. Subbase materials are firmer than weak soils, but on clay subgrades there is a tendency for the soil to work up into the openings in the subbase and thus diminish its value. Under concrete, the small additional load distribution furnished by a subbase seldom makes its use economical. Crack surveys on a concrete road built in Ohio on subbases of various types showed at the end of 5 years that a granulated-slag subbase was quite beneficial in decreasing cracking, whereas the effects of a subbase of sand, gravel, or a mixture of cement and clay were decidedly uncertain.

HARD PAVEMENTS

(PART 2)

Serial 2773 B Edition 2

BITUMINOUS PAVEMENTS

HOT-MIX BITUMINOUS PAVEMENTS

GENERAL CHARACTERISTICS

1. **Types of Bituminous Pavements.**—The bituminous pavements comprise the various bituminous-concrete types, including sheet asphalt, graded-stone mixes laid either hot or cold, natural rock asphalt, and asphalt block. A bituminous-concrete pavement is one having a wearing course composed of a mixture of asphalt cement and mineral aggregate that is prepared before it is laid. The plant-mixed low-cost surfaces are, in a sense, bituminous concretes, but they are not generally so classed.

2. **Kinds of Hot-Mix Bituminous Pavements.**—There is a large variety of hot-mix bituminous-concrete pavements. For the sake of simplicity in classification, these pavements may be divided according to the grading of the aggregate into the following three groups: (1) sheet asphalt, in which all the aggregate is so fine that it passes a 10-mesh sieve; (2) fine-graded bituminous concrete, in which the maximum size of the aggregate is $\frac{1}{2}$ inch; (3) coarse-graded bituminous concrete, in which aggregate as large as $1\frac{1}{4}$ to $1\frac{1}{2}$ inches is used. The comparative grading characteristics of the three classes of mixtures are shown in Fig. 1. A sheet-asphalt wearing course *a* on a binder course *b* is indicated in view (*a*), a fine-graded bituminous concrete in view (*b*), and a coarse-graded bituminous concrete in view (*c*).

3. Advantages of Bituminous-Concrete Pavements.—A bituminous-concrete pavement may be opened to traffic a few hours after it is completed. Such a pavement resists quite well the impact and abrasive action of traffic, and wears slowly and uniformly. Also, it may be easily repaired and cleaned. Therefore, the maintenance cost is low.

Fig. 1

4. Typical Cross-Sections of Bituminous-Concrete Pavements. A bituminous-concrete wearing course must have a substantial base. Most bituminous-concrete surfaces are laid on a portland-cement concrete base or on a so-called black base of bituminous concrete. However, an existing surface of brick or stone blocks can often be utilized to advantage as a base for a bituminous-concrete road; also, a base of macadam, telford, or well-compacted gravel that is of adequate thickness and is properly drained may be satisfactory. Ordinarily, the wearing course rests directly on the base course, but sometimes it is laid on an intermediate binder course.

In the construction illustrated in Fig. 2 (*a*), the 2-inch bituminous-concrete wearing course *a* is placed directly on the 3-inch to 8-inch concrete base *b*; whereas in view (*b*) is shown a $1\frac{1}{2}$-inch binder course *c* between the $1\frac{1}{2}$-inch surface course *a* and the base *b*. The edging at each end of the concrete base in both types of construction may be either integral with the base, as in view (*a*), or separate, as in (*b*). Where the base is an old broken-stone or gravel road to which new material is added to provide adequate thickness, the usual construction is as illustrated in view (*c*). The old and new material in the base *b* should be equivalent to a base of new material at least 6 inches

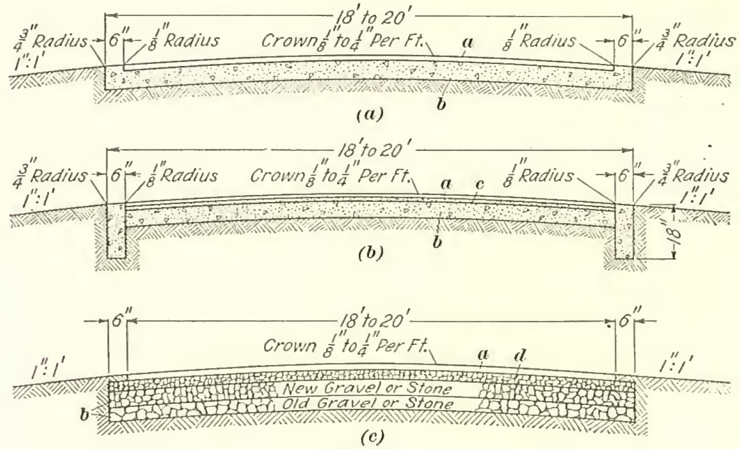


Fig. 2

thick, and a course *d* of compacted stone 2 to 3 inches thick should be introduced between the base and the 2-inch wearing surface *a*.

SHEET ASPHALT

5. Use of Binder Course.—When the wearing course is of sheet asphalt, it is customary to provide also a binder course of bituminous concrete and to make each of these two courses $1\frac{1}{2}$ inches thick. The purpose of the binder course is to even up the irregularities in the surface of the base course and to prevent shoving or creeping of the wearing course. However, with the present methods for securing a true surface finish on the base course, the binder course is not needed and is frequently omitted.

6. Materials for Binder Course.—The bituminous concrete used for the binder course of a sheet-asphalt pavement may be

of either the open or the closed type. The open binder, as the name implies, has an open or porous texture, being composed of crushed stone and bituminous cement without sand; whereas the closed binder, which is the type most commonly used, is composed of a fairly well-graded mixture of broken stone, sand, and bituminous cement, and has a rather close texture. Either broken stone or broken slag may be used for the coarse aggregate for the binder course. A typical grading, by weight, for this aggregate is as follows:

Passing a $1\frac{1}{2}$-inch screen	100 per cent.
Passing a $1\frac{1}{4}$-inch screen	95 to 100 per cent.
Passing a $\frac{3}{4}$-inch screen	40 to 75 per cent.
Passing a $\frac{1}{4}$-inch screen	0 to 5 per cent.

Any material passing the $\frac{1}{4}$-inch screen is, for the purpose of proportioning the mixture, considered as fine material. The fine aggregate for the binder course is composed of clean sand, of which 100 per cent. passes the $\frac{1}{4}$-inch screen and from 0 to 6 per cent. passes the 200-mesh sieve. The materials for the binder course are combined in such proportions as to produce a mixture conforming to the following composition limits by weight:

Aggregate retained on a 10-mesh sieve	60 to 80 per cent.
Aggregate passing a 10-mesh sieve	15 to 35 per cent.
Bitumen (soluble in carbon disulphide)	4 to 7 per cent.

The exact composition of the binder course will depend on the character of the aggregate and can only be determined by trial by the engineer in charge of the mixing plant. The comparative grading of the material in an open binder for a sheet-asphalt pavement is shown in Fig. 1 (*a*) at *b*.

7. Materials for Wearing Course.—The wearing course for a sheet-asphalt pavement is composed of sand, mineral filler, and asphalt cement. The sand should consist of clean, tough, rough-surfaced, and angular particles. Since the inherent stability of the aggregate is increased when its volume of voids is decreased, the aggregate should be so graded in size as to have a small percentage of voids when it is compressed. The proportions, by weight, of the different sizes of particles may vary within wide limits. But, the total aggregate passing the 10-mesh sieve and retained on the 40-mesh sieve should be from 18 to 50 per cent.; passing the 40-mesh sieve and retained on the 80-mesh sieve, 30 to 60 per cent.; and passing the 80-mesh sieve and retained on the 200-mesh sieve, 15 to 40 per cent.

The mineral filler consists of limestone dust, dolomite dust, or portland cement. All of the filler should pass a 30-mesh sieve and 65 to 100 per cent. should pass a 200-mesh sieve. The filler serves to fill the voids in the sand and to increase its internal friction. However, most mineral fillers contain a high percentage of voids and the use of too much filler may defeat the purpose for which it is intended.

The stability of a sheet-asphalt wearing course depends to a considerable extent on the consistency of the asphalt which binds the grains of sand together. A soft asphalt will permit deformations of the surface under traffic, whereas too hard an asphalt will produce a brittle mixture that will become badly cracked. The grade of asphalt cement that should be used depends somewhat on climatic and traffic conditions. The Asphalt Association recommends the following ranges in penetration:

Traffic	Penetrations		
	Low Temperature	Moderate Temperature	High Temperature
Light	50 to 60	50 to 60	40 to 50
Moderate	50 to 60	50 to 60	40 to 50
Heavy	40 to 50	40 to 50	30 to 40

The penetrations in this case, as in all other cases where the conditions are not specified, are the distances in hundredths of a centimeter that a needle loaded to weigh 100 grams will penetrate in 5 seconds at a temperature of 25° C., or 77° F.

8. The volume of asphalt to be used should be slightly less than the volume of voids in the compressed mixture of sand and filler, because the stability of the wearing course is greatly

reduced when the asphalt more than fills the voids. Provided the stability is not reduced, however, the durability of the mixture is improved by increasing the quantity of asphalt. Therefore, the desired percentage of voids in the sand and filler should be established so as to obtain both stability and durability to a reasonable degree. The proportions, by weight, of the constituents of a sheet-asphalt wearing course should be such as to produce a mixture conforming to the following requirements:

Material	Passing	Retained on	Per Cent. of Total Mixture
Aggregate	10-mesh sieve	40-mesh sieve	10 to 40
	40-mesh sieve	80-mesh sieve	20 to 48
	80-mesh sieve	200-mesh sieve	12 to 36
Aggregate and filler	200-mesh sieve		10 to 18
Bitumen (soluble in carbon disulphide)			$9\frac{1}{2}$ to $12\frac{1}{2}$

As in the case of the binder course, the exact proportions of the mixture will depend on the character of the aggregate and can only be determined by preparing trial mixtures in the laboratory and testing them for stability and voids.

9. **Construction of Binder Course.**—The coarse and the fine aggregates for the binder course are dried and heated at the mixing plant in revolving drums in which the materials are continuously agitated during the heating. The usual temperature to which the aggregate is heated is between 225° and 350° F. After being heated, the aggregate is screened and combined in batches by weighing, and the batches are conveyed into the mixer where the required quantity of hot asphalt is added. The mixing is done in approved batch mixers of the rotary-drum type for at least 45 seconds or until all the particles are uniformly coated. The temperature of the completed mixture is usually between 250° and 325° F.

The binder-course mixture is transported from the mixing plant to the job in tight vehicles, and is dumped on steel dump sheets outside the area on which it is to be spread. It is then

immediately distributed into place by means of hot shovels and spread with hot rakes or a finishing machine in a uniformly loose layer to a depth that will be reduced to about $1\frac{1}{2}$ inches after compaction. While it is still hot, the binder is rolled with a three-wheel roller having a weight of 10 or 12 tons and then with a tandem roller weighing about 8 tons. The rolling should start at the sides and proceed longitudinally toward the center by overlapping on successive trips by about one-half the width of the wheel. The course should then be subjected to a diagonal rolling in two directions, so that the second diagonal rolling crosses the lines of the first. In order to prevent the asphalt from adhering to the wheels of the roller, they should be mopped or sprayed with kerosene and water during the rolling process. The rolling is an important part of the work and should be done by competent and experienced operators. Around curbs and manholes and in other places not accessible to the roller, it is necessary to tamp the mixture by hand with hot tampers weighing about 50 pounds.

Where it is necessary to suspend operations long enough for the mixture to become chilled, a joint is formed, before work is resumed, by cutting back on a slight bevel so as to expose the full depth of course, and painting the exposed edge with hot asphalt against which the fresh mixture is tamped. After a section of binder course has been laid and compacted, the surface trueness is tested with a template and a 10-foot straightedge and all irregularities more than $\frac{1}{4}$ inch below the straightedge are corrected.

10. **Construction of Wearing Course.**—The sand for the sheet-asphalt mixture is heated in the revolving drum to a temperature of 325° to 400° F., and is then combined with the mineral filler in uniform batches, the materials being weighed separately. After the proper amounts are conveyed to the mixer and mixed thoroughly, the hot cement is added and the mixing is continued for at least 1 minute or as long as is necessary to produce a homogeneous mixture in which all the particles are uniformly coated. The temperature of the completed mixture should be between 300° and 375° F. The mixture is delivered

to the job, dumped, and spread in the same manner as described for the binder course. All contact surfaces of curbings, gutters, manholes, etc., are painted with hot asphalt just before the mixture is placed against them. The course is then rolled while hot, first with a 10-ton or 12-ton tandem roller and then with an 8-ton machine. During the rolling, the surface is tested for trueness, and irregularities are corrected. A light coating of portland cement has often been swept upon the surface before final compaction, but the value of this coating is questionable.

FINE-GRADED BITUMINOUS CONCRETE

11. **Character of Materials.**—The most common type of fine-graded bituminous concrete, and one which has been successfully used for many years, is known as Topeka. It is composed of crushed aggregate up to ½ inch in size, sand, mineral filler, and asphalt cement. The coarse aggregate may consist of broken stone, broken slag, or gravel, but gravel is not usually so satisfactory for this type of pavement. A typical grading specification of the aggregate and mineral filler for a Topeka mix is as follows:

Passing	Retained on	Per Cent.
½-inch screen	¼-inch screen	5 to 10
¼-inch screen	10-mesh sieve	11 to 25
10-mesh sieve	40-mesh sieve	7 to 25
40-mesh sieve	80-mesh sieve	11 to 36
80-mesh sieve	200-mesh sieve	10 to 25
200-mesh sieve		5 to 11

The material passing the 200-mesh sieve is the mineral filler and is usually composed of limestone dust or portland cement, the same as for sheet asphalt.

The required amount of bituminous material varies with the conditions, as explained for sheet asphalt, but the proper weight for Topeka is usually between 7 and 11 per cent. of the total weight of the mix. The required consistency of the asphalt cement will depend somewhat on the climatic and traffic conditions, but for usual conditions the penetration should be about

the same as for the bituminous material in a sheet-asphalt wearing course.

12. **Construction Features.**—Topeka is commonly laid without a binder course, and the wearing course, which is placed in a single application, is usually 2 inches thick. The materials that make satisfactory base courses for sheet asphalt are also suitable for Topeka, and about the same thickness of base is required for the two surfacings.

The methods of heating and mixing the ingredients, of transporting the mixture to the road, of dumping and spreading it, and of rolling and finishing the surface are essentially the same as those described for sheet asphalt.

COARSE-GRADED BITUMINOUS CONCRETE

13. **Requirements for Materials.**—The coarse-aggregate bituminous mixes are composed of crushed stone or slag up to 1¼ or 1½ inches in size, sand, mineral filler, and bituminous cement. There are many different specifications in use, but a typical composition is as follows:

Material	Passing	Retained on	Per Cent. of Total Mixture
Aggregate	1¼-inch screen	¼-inch screen	55 to 65
	¼-inch screen	10-mesh sieve	5 to 15
	10-mesh sieve	200-mesh sieve	20 to 30
Aggregate and filler	200-mesh sieve		4 to 6
Bitumen (soluble in carbon disulphide)			5 to 8

It is further required that the weight of aggregate passing the 1¼-inch screen and retained on the ¾-inch screen should be from 15 to 45 per cent. of the total weight of the mixture; and that the weight passing the ¾-inch screen and retained on the ¼-inch screen should likewise be from 15 to 45 per cent. of the total. Also, the portion of the fine aggregate passing the 10-mesh sieve, with the mineral filler added, should meet the following requirements:

Material	Passing	Retained on	Per Cent.
Aggregate	10-mesh sieve	40-mesh sieve	15 to 40
	40-mesh sieve	80-mesh sieve	22 to 53
	80-mesh sieve	200-mesh sieve	15 to 40
Aggregate and filler	200-mesh sieve		10 to 15

The exact amounts used in batching are influenced by the character of the aggregate, and the proportions within the preceding range limits must be designated by the engineer in charge of the mixing plant.

The bituminous material for this type of pavement should have a penetration between 50 and 80, depending on the traffic and temperature conditions of the locality. Under usual conditions a penetration between 50 and 60 for heavy traffic or between 60 and 70 for light traffic should prove satisfactory. A typical specification for heavy traffic for the climate around Washington, D. C., is as follows:

Designation	Petroleum Asphalt	Fluxed Native Asphalt
Specific gravity 25°/25° C.	Not less than 1.01	1.05 to 1.07
Flash point, not less than.........	175° C.	175° C.
Softening point	40° to 60° C.	45° to 55° C.
Penetration at 25° C. under 100 grams in 5 seconds	50 to 60	50 to 60
Ductility at 25° C., not less than..	40	40
Loss at 163° C. in 5 hours, not more than	1 per cent.	3 per cent.
Penetration of residue at 25° C., under 100 grams in 5 seconds, as compared to penetration before heating, not less than	60 per cent.	50 per cent.
Bitumen (soluble in carbon disulphide), not less than	99.5 per cent.	94 per cent.
Organic matter insoluble, not more than	.2 per cent.	....
Inorganic matter insoluble	....	2.5 to 4 per cent.

14. General Features of Construction.—The wearing course of a coarse-graded bituminous-concrete pavement is laid directly on a suitable base without the introduction of a binder course. The aggregates are dried, heated, and mixed with the bituminous material at the mixing plant, hauled to the job, and laid at a temperature between 225° and 325° F. The material should be dumped on dumping boards ahead of the operations and shoveled into place as described for sheet asphalt. This course is generally laid so as to produce a compacted depth of 2 inches. Usually, an allowance of about 25 per cent. must be made for compaction, and therefore the loose depth will be about $2\frac{1}{2}$ inches. The initial compression is made with a 10-ton to 12-ton roller of either the tandem or three-wheel type, and final compression is made with a 6-ton to 8-ton tandem roller. The formation of joints, the procedure around curbs and manholes, and the correction of irregularities are carried out in the same manner as previously described for sheet asphalt.

On coarse-graded bituminous concrete it is customary to place a finish coat just after the initial rolling. This coat tends to give the pavement a non-skid surface. A seal coat of asphalt cement may be used with a blotter of pea gravel or slag screenings, but the present trend is in favor of a bituminous-mixture finish coat composed of stone or slag chips $\frac{1}{2}$ inch in size, mixed with $1\frac{1}{2}$ to 2 per cent. of asphalt cement in the same manner as described for the main course. The finish should be applied hot at the rate of approximately 10 pounds per square yard.

15. Warrenite-Bitulithic Pavement.—One of the best known types of coarse-graded bituminous concrete is the patented pavement called Warrenite-Bitulithic. This pavement consists of a 2-inch layer of coarse-graded mixture, which is combined with a thin layer or seal coat of fine-graded mixture similar to that used for a sheet-asphalt wearing course. The special feature of the Warrenite-Bitulithic pavement is the blending together of the two layers by compression. The bituminous cement, known as Bitulithic cement, that is used for this construction is especially prepared under the supervision of Warren Brothers Company. The mixture for the first course is prepared

and placed in much the same manner as previously described for non-patented mixtures. While this mixture is still in a malleable condition, and before it has been compacted to an extent that would prevent the essential blending and bonding of the fine-graded mixture, it is covered with the prepared surface mixture at the rate of 30 to 50 pounds per square yard. The

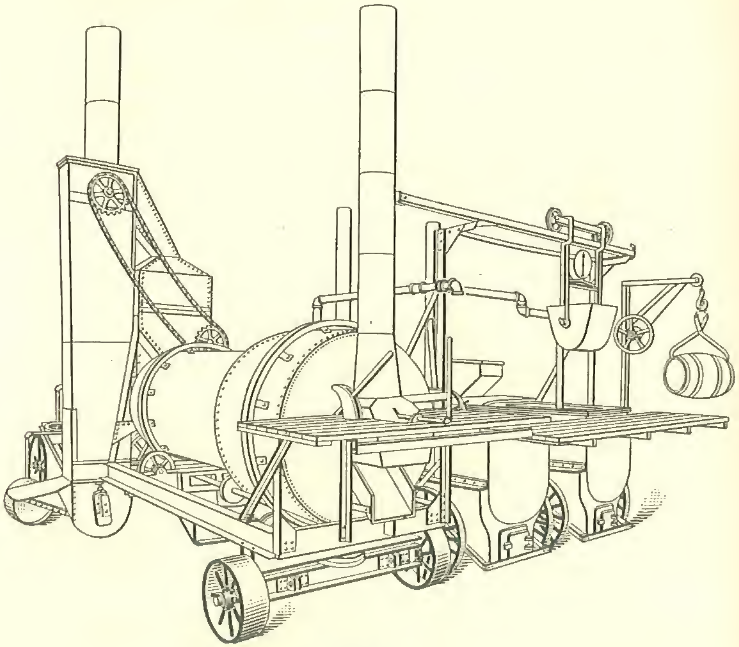


Fig. 3

material is then thoroughly compacted by rolling. After the pavement has received the final compression, a small quantity of stone dust or portland cement is swept over the surface.

MIXING PLANTS FOR BITUMINOUS CONCRETE

16. Types of Mixing Plants.—For the first-class construction of any hot-mix bituminous pavement, a well-equipped and scientifically operated paving plant is essential. Complete installations are supplied by a number of concerns. They are of three

general types, namely, permanent, railway, and portable or semiportable.

The permanent plant is suitable mainly in connection with city pavement work, where the material has to be supplied for only a restricted area. The settings are usually stationary and the equipment is heavier and more substantial than that for the other types of plants. Railroad plants are mounted on railroad trucks and are operated at a railroad siding. Portable plants

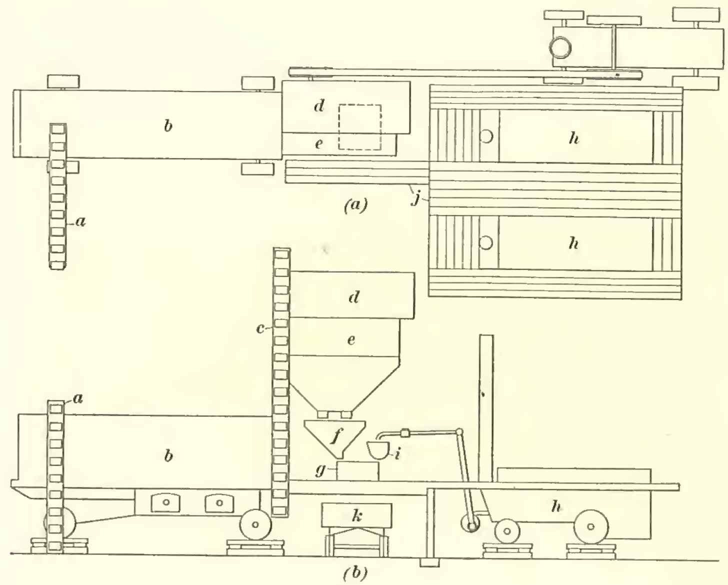


Fig. 4

are of smaller capacity than the others and are constructed in two, or sometimes three, separate units to facilitate movement from place to place; in Fig. 3 is illustrated a typical portable plant. The general features of construction and operation are essentially the same for all types of plants.

17. Handling Aggregate.—A typical layout for a portable mixing plant is shown diagrammatically in Fig. 4, in plan in view (*a*) and in elevation in (*b*). The mineral aggregate is fed by means of an elevator *a*, usually of the belt and bucket type, into the dryer *b*. This consists of a revolving metal drum

through which a stream of hot air or hot exhaust gases is forced constantly. The drum is provided with baffle plates so that the aggregate is thrown about and not only is heated by contact with the hot metal but also is dried by contact with the gases. Since the temperature of the aggregate prior to mixing is very important, a pyrometer is installed at the discharge end of the drum to indicate the temperature of the material. Sometimes the gases leaving the drum are passed through a dust collector, as they often carry off considerable dust from the aggregate.

In the case of a coarse-graded mixture, the fine and coarse aggregates are usually fed to the dryer separately because of the tendency for the larger particles to segregate from the smaller ones during the passage through the drum. However, all the aggregate may be heated together if, after being discharged from the dryer onto the elevator *c*, it is carried first to the screen chamber *d*, where it is again sorted into sizes, then to storage bins *e*, and finally to the measuring hopper *f*, before the different sizes are again combined in the mixer *g*. The fine and coarse aggregates for a Topeka mix are generally heated together in the proper proportions, measurement being made by shovels.

18. **Handling Asphalt.**—The asphalt is heated to a fluid state, and sometimes fluxed to a desired consistency, in one or more tanks or kettles *h*, Fig. 4. These tanks may be heated by direct fire, but it is preferable to use steam coils for this purpose. An agitating device should be provided to prevent settlement of non-bituminous material and to assist in the fluxing process. Agitation is usually secured by forcing jets of steam or air through the heated material from perforated pipes located near the bottom of the tank. After the asphalt cement has been melted or fluxed, it is maintained at the proper temperature until used in the mix. It is generally lifted by air pressure or a special hoisting device directly from the tank to a weighing bucket *i*, which is emptied into the mixer.

19. **Mixing Equipment.**—The operations for proportioning the materials and feeding the mixer are conducted from a platform *j*, Fig. 4, set above the mixer. Formerly, mixers of the pug-mill type were commonly employed, but rotary-drum mixers

that are suitable for bituminous concrete have been developed and are coming into extensive use. The hot concrete that is discharged from the mixer is allowed to drop into trucks or wagons *k*, in which it is delivered to the road.

Some paving plants are equipped with a rotating horizontal drum which is divided by means of a diaphragm into a drying compartment and a mixing compartment. A measured amount of mineral aggregate is correctly proportioned and fed into the drying end of the drum, where it is heated. The heated aggregate is then fed into the mixing compartment of the drum through a gate in the diaphragm, the asphalt cement is added, and the materials are mixed. Each batch of aggregate can be heated while the preceding batch of concrete is being mixed.

FINISHING MACHINES FOR BITUMINOUS-CONCRETE PAVEMENTS

20. During recent years, machines have been developed for finishing bituminous-concrete pavements. These machines spread and rake the mixture, and smooth the surface. Their use permits a material speeding up of the progress of the work and gives a much more accurate riding surface than that produced by hand-raking methods. The two principal types of machines are known, respectively, as the pendulum and sliding types; the essential difference between them is in the details of operation of the mechanical rake. In both types, the rake teeth are placed in two rows, not over 6 inches apart, and are inclined to the road surface so that they tend to lift the coarser aggregate to the surface of the mixture. However, in the pendulum type, the rake teeth swing forwards and backwards with a pendulum motion, the two lines moving in opposite directions; whereas, in the sliding type, both lines of teeth slide forwards and backwards together, the mixture being lifted only on the forward stroke. In Fig. 5 is shown a typical finishing machine for bituminous-concrete pavements.

21. The important parts of a finishing machine are illustrated diagrammatically in Fig. 6. Where machine finishing is to be adopted, the bituminous mixture is brought to the road in trucks and is spread roughly, to a depth about 2½ inches greater

than the compacted thickness of the course, by means of spreader boxes similar to those used for crushed stone. The loose depth of the material is made somewhat greater than is usual for hand finishing, because it is necessary that a rather high wave of the mixture be carried in front of the forward screed *a* on the machine. The rake *b* forms longitudinal ridges and furrows in the road surface, and the rear screed *c* knocks the tops off the ridges and evens the surface. To insure trueness of finish, it is essential to have the machine run on side forms that are usually

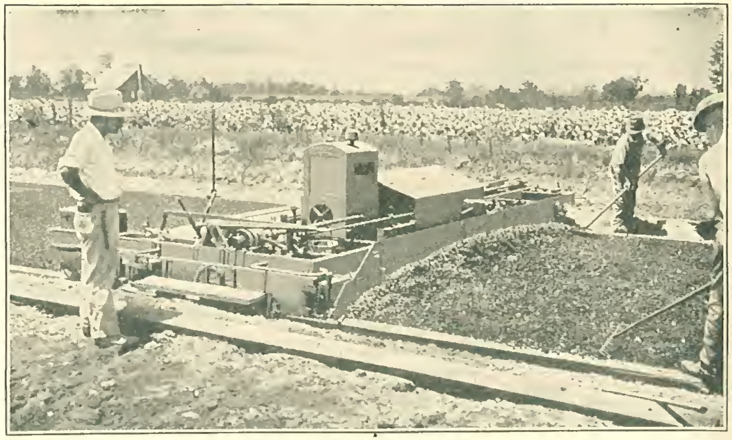


Fig. 5

of steel and are set and held accurately to line and grade. The wheels *d* rest on top of the forms and roll along them. As soon as a sufficient length of road has been covered by the machine, the surface is rolled.

ROCK-ASPHALT PAVEMENTS

INTRODUCTION

22. Supply of Rock Asphalt.—When sandstone or limestone has been impregnated with asphalt by nature, it is known as rock asphalt. This material has been used for many years in Europe for surfacing city streets. In recent years, rock-asphalt pavements have been built quite extensively in rural road improvement in the United States, where the principal sources

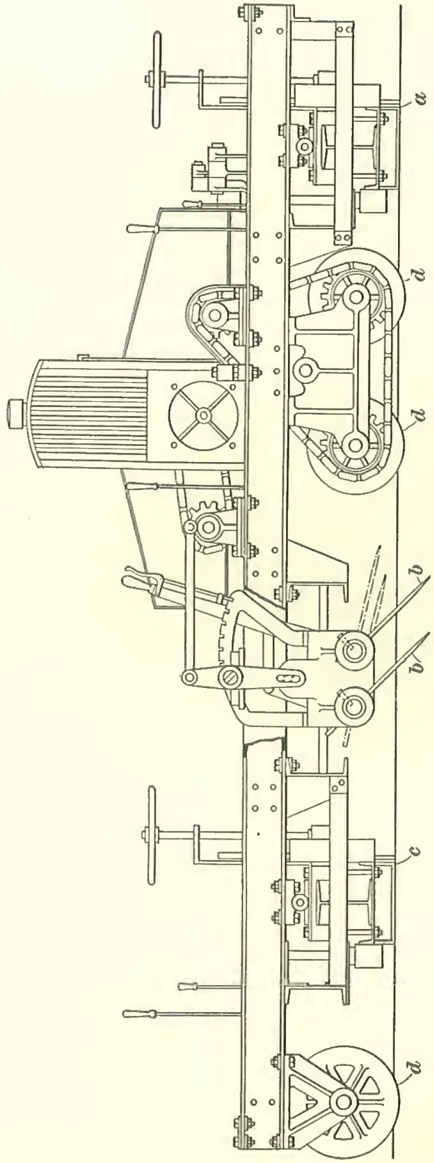


Fig. 6

of supply of rock asphalt that have been developed on a commercial scale are located in Kentucky, Texas, Oklahoma, California, and Alabama. As all the material for the surfacing of rock-asphalt pavements must be shipped from the asphalt deposit, the use of such pavements in this country has been restricted largely to those states and to neighboring states; in other parts of the country, it is more economical to build pavements in which local sources of aggregate can be used. Also, since the rock asphalts obtained from different quarries vary widely in mineral content and in the amount and character of the asphaltic binder, the methods of constructing rock-asphalt pavements are not uniform.

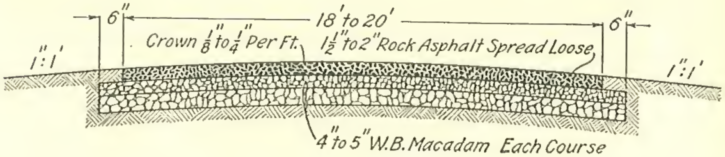


FIG. 7

23. Cross-Sections of Rock-Asphalt Pavements.—When a rock-asphalt pavement is laid either on a portland-cement concrete base or on an old broken-stone or gravel base that has been reshaped, the cross-section is similar to that shown in Fig. 2 (*a*) or (*c*) for typical bituminous-concrete pavements. The thickness of the rock-asphalt wearing course is usually from $1\frac{1}{2}$ to 2 inches when the material is spread loose, and the thickness of the base course is as stated in Art. 4. When the base is of new waterbound macadam, the construction shown in cross-section in Fig. 7 is generally employed. The base is built in two courses, each 4 to 5 inches thick, and the wearing course is laid directly on the base.

KENTUCKY ROCK ASPHALT

24. Characteristics of Material.—The best-known Kentucky rock asphalt is mined near Bowling Green on the Green River, which is a tributary of the Ohio River. Although the impregnation of asphalt in the beds is somewhat irregular, the lean and rich portions are sorted and combined when the rock is crushed and ground, and the commercial product has a fairly uniform asphalt content. The aggregate is sandstone.

The composition of the ground rock generally resembles that of a sheet-asphalt mixture, but the grading of the mineral aggregate cannot be so thoroughly controlled and therefore this resemblance is not always obtained. The extracted asphalt is too soft for the penetration test, and its consistency, as determined by the float test, is about 180 seconds.

On account of the softness of the asphalt, the proportion of bitumen in Kentucky rock asphalt is kept down to between 7 and 9 per cent. A greater amount is a serious detriment in that it causes surface displacement and soft spots in the pavement, probably because the soft asphalt coats each particle of stone more thoroughly and with a thinner film than when a stiff asphalt is used, and therefore an excess is more readily apparent.

25. Method of Construction.—The prevailing practice in the use of Kentucky rock asphalt has been to employ a broken-stone base, which may be either new construction or reshaped worn macadam. In both cases the method is essentially the same. The base course of crushed stone is only partly filled with screenings, so that the coarse stone of the base projects into the surface layer and provides a certain anchorage that prevents major displacement of the asphalt on the base. The ground rock asphalt is applied cold and rolled.

Kentucky rock asphalt has in some cases been laid on a concrete base. The surface of the concrete is finished fairly rough or is painted sparingly with a cut-back asphalt to insure adhesion of the surfacing to the foundation. Old brick pavements, waterbound and bituminous macadam, modified telford, and occasionally gravel roads have been utilized to support rock-asphalt paving. Either scarification and compaction under traffic or, in the case of a base such as old brick, the addition of a leveling-up course is advisable to prepare the old subgrade for the wearing surface.

UVALDE ROCK ASPHALT

26. Uvalde rock asphalt is mined near Kline, Uvalde County, in southwestern Texas. The aggregate, which is limestone composed of coral and shell sand, is comparatively soft. However, the asphalt has considerable hardness, the value of the penetration being from 5 to 15 with an average of 8, and it impregnates not only the rock particles but also the interstices between them. Hence, sufficient toughness is imparted to the rock. The asphalt content of the material shipped from the mines for wearing-course construction ordinarily runs from 12 to 15 per cent. by weight.

27. The first process after mining is the crushing of the material in specially designed pulverizers into particles with a maximum size of about $\frac{1}{2}$ or $\frac{1}{4}$ inch. Various methods of laying the material have been successfully employed. In the typical early practice, the material was heated, a very fluid flux was added, and the mass was mixed in a mixer, such as is generally used for bituminous concrete. The added flux served to soften the exposed particles of asphalt and aided in the proper consolidation of the mixture under rolling. However, the coarser fragments of rock asphalt were softened only at their surfaces, and thus the resulting pavement structure resembled well-proportioned asphaltic concrete and was comparatively immune from lateral displacement, although the surface resembled a sheet asphalt. Recent practice in Texas, where most of the Uvalde material is used, has inclined toward the cold process; but, according to standard specifications, the heating of the aggregate is optional with the engineer.

The surface of the existing base, whether concrete, macadam, or gravel, is thoroughly cleaned and then treated with one or two applications of hot asphaltic oil at the rate of about $\frac{1}{10}$ gallon per square yard. This treatment is followed by a light application of finely pulverized rock asphalt, forming a layer about $\frac{1}{4}$ inch thick, which is ordinarily allowed to consolidate under traffic. The material for the additional thickness of pavement is passed through a pug-mill mixer where 1 to 2 per cent., by weight, of fluxing oil is added. After this material has been spread and the surface has been rolled, a top dressing of limestone-asphalt dust, free from flux, is rolled into the surface until all excess bitumen is absorbed and the desired compaction is produced.

OKLAHOMA ROCK ASPHALT

28. Oklahoma rock asphalt is mined near Daugherty and in other localities of southern Oklahoma. There are two kinds, namely, bituminous sandstone and bituminous limestone. The materials are found in separate deposits located some distance apart and have been used both in combination and separately. The trend seems to be toward the adoption of the limestone because of the unsatisfactory grading of the impregnated sandstone thus far encountered. Both of these types are fine grained. The asphaltic content is uniformly close to 5 per cent. by weight in both the sandstone and the limestone deposits. In both cases the extracted asphalt is too soft for the penetration test and has a consistency, by the float test, of about 225 seconds.

Where used in combination, the two materials are crushed together in predetermined proportions. The size of the coarsest particles is $\frac{1}{2}$ inch. The pulverized material is shipped, usually by rail, to the site of the improvement. There it is heated to a temperature of from 225° to 325° F., and mixed in a pug-mill mixer. Sufficient asphalt having a penetration of 40 to 60 is added to bring the bituminous content up to between 8 and 11 per cent.

When either material is used alone, it is usually heated and mixed with additional asphaltic binder in the manner just described for a combination of the materials. However, the cold-laying process has been employed without the addition of asphalt, and such pavements have given satisfactory service.

The composition and final appearance of the pavements constructed of Oklahoma rock asphalt resemble a modified Topeka pavement, as these pavements include, according to predetermined proportions, stone fragments between the $\frac{1}{2}$-inch and 10-mesh sizes in amounts up to about 32 per cent. The interlocking effect of the crushed stone fragments no doubt explains the freedom from surface displacement.

COLD-LAID BITUMINOUS PAVEMENTS

TYPES OF COLD-LAID MIXTURES

29. Cold-laid bituminous mixtures have been used for many years in Europe and to a somewhat limited extent in the United States. In comparatively recent years, however, there has been considerable promotion of various cold-laid mixtures, and there is every indication that the use of this type of pavement will continue to increase in the United States. Besides the rock-asphalt type, which is usually laid cold, there are numerous other types, mostly patented, that are now being laid cold in this country. In the preparation of these cold-laid mixtures, use is made of cut-back tar, cut-back asphalt, fluxed asphalt, emulsified asphalt, and powdered asphalts with fluxes or liquefiers of various kinds. All these cold-laid mixtures contain volatile oils, liquefiers, or water that retard the hardening of the bituminous material until the mixture has been laid. Because of this retarded hardening, the aggregate may be mixed with the bitumen at a central plant located at a quarry many miles away from the job, shipped cold in trucks or freight cars to the road to be surfaced, and laid on the road with very little interruption of traffic and without the necessity of setting up a mixing plant near-by. The shipped-in cold mixture is especially advantageous for small jobs where a mixing plant would be expensive. It is also a convenient type for large projects.

AMIESITE

30. One of the oldest and best known of the cold-laid types of bituminous surfaces is the Amiesite mixture, which is composed of crushed stone, liquefier, and asphalt cement. The stone is dried at the mixing plant; is run into the mixer, where it is coated with a liquefier of crude naphtha, kerosene, gasoline, or a mixture of these oils; and then is mixed thoroughly with hot asphalt cement and a small amount of powdered hydrate of lime. When the materials enter the mixer, the temperature of the stone is around 100° F. and that of the asphalt cement is usually around 300° F. After the mixing is completed, the coated stone is loaded into cars or trucks and shipped to the job.

It is customary to lay Amiesite in two courses, namely, a binder course about $1\frac{1}{2}$ inches thick, and a wearing course $\frac{1}{2}$ to $\frac{3}{4}$ inch thick. For the binder course, the crushed stone is graded from 2 inches to $\frac{1}{4}$ inch, and about 70 per cent. is larger than 1 inch; for the wearing course, the aggregate is graded from $\frac{3}{4}$ inch down to the 20-mesh size, and about 95 per cent. passes the $\frac{1}{4}$-inch screen. The bitumen content in the binder course will be around 4 per cent. of the total material, and in the wearing course about $5\frac{1}{2}$ per cent. The hydrated lime amounts to less than 1 per cent. of the total and is used to facilitate the coating of stone with the asphalt cement. Amiesite is usually laid on a concrete base, but worn-out brick, stone block, or compacted macadam may be used.

CUT-BACK ASPHALT COLD MIXTURE

31. Cut-back asphalt surfacing material that is to be laid cold is made by mixing the mineral aggregate, which may be crushed stone, slag, or gravel, with asphalt cement that is cut back with naphtha or some other volatile oil. This type of surfacing is usually mixed cold in an ordinary cement-concrete mixer; but, for small jobs, it may be mixed on a mixing board with shovels. The usual specification for the aggregate is as follows:

Passing a $1\frac{1}{4}$-inch screen	100 per cent.
Passing a $\frac{3}{4}$-inch screen	35 to 75 per cent.
Passing a $\frac{1}{4}$-inch screen	10 to 35 per cent.
Passing a 10-mesh sieve	0 to 2 per cent.

The quantity of cut-back asphalt should be approximately 7 per cent. by weight of the total mixture, or there should be about 1 gallon of asphaltic material to 100 pounds of stone.

The cut-back mixture is laid on the prepared base course in a 2-inch layer. It must be carefully raked to a uniform surface and then rolled with a 10-ton power roller. Some engineers prefer to mix the material and store it in piles under cover for a few days, in order to allow some of the volatile oil to evaporate before the mixture is laid. Less time is then required for the mixture to harden after it is laid, and traffic need not be kept off

the finished road for so long a period as would be necessary if the material were laid as soon as mixed.

CUT-BACK TAR COLD MIXTURES

32. **Tarvialithic.**—Cut-back tar may be used instead of cut-back asphalt in providing a cold-laid bituminous surfacing. The better known examples of cold-laid bituminous mixtures in which tar is the binder are Tarvialithic, Tarmac, and Slagmac.

The Tarvialithic mixture somewhat resembles Amiesite in its general characteristics, except that tar is used as the binder. The mixture is laid in two courses, namely, a binder course and a wearing course. Usually, the total thickness is about 2 inches, although sometimes it is $2\frac{1}{2}$ or even 3 inches. The binder-course aggregate is graded from $1\frac{1}{4}$ inches to the 10-mesh size, and the wearing-course material is graded from $\frac{1}{2}$ inch down to the 200-mesh size. The bitumen content in the binder is around 3 per cent. of the total weight and in the wearing course it is between 6 and 7 per cent.

33. **Tarmac.**—The cold-laid cut-back tar mixture that is known as Tarmac is also laid in two courses, a binder course $1\frac{1}{2}$ inches thick and a wearing course $\frac{1}{2}$ inch thick. The aggregate for the binder course is crushed stone or slag that is uniformly graded from $1\frac{1}{4}$-inch to 10-mesh size and about 80 per cent. of which is larger than $\frac{1}{2}$ inch. For the wearing course, the aggregate is uniformly graded from $\frac{1}{2}$-inch to 10-mesh size, and 75 per cent. is between $\frac{1}{2}$ and $\frac{1}{4}$ inch, 20 per cent. is between $\frac{1}{4}$-inch and 10-mesh sizes, and 2 per cent. passes the 10-mesh sieve. The bitumen content in the binder course is between 2 and 3 per cent., and in the wearing course between 3 and 4 per cent. After the final rolling, the road is opened to traffic for about a week, and then a filler of sand mixed with a small amount of tar is cast over the surface of the pavement to fill the surface voids.

34. **Slagmac.**—The surfacing called Slagmac is composed of crushed slag and cut-back tar. It is laid in two courses whose respective thicknesses are $1\frac{1}{2}$ inches and $\frac{1}{2}$ inch. The slag is uniformly graded from 2 inches to $\frac{1}{4}$ inch for the binder course and from $\frac{1}{2}$-inch to 200-mesh size for the wearing course. The bitumen content for the binder course is between 4 and 5 per cent. and for the wearing course between 6 and 7 per cent.

COLD BITUMINOUS MIXTURES USING ASPHALT EMULSIONS

35. An asphalt emulsion must be sufficiently stable to stand storage and transit without breaking down, and yet must be unstable enough to break soon after being placed on the road. Emulsions contain from 50 to 70 per cent. of asphalt, and their extreme fluidity permits a complete and rapid coating of the aggregate even under adverse conditions. They have been used in the United States for many years for making patches on bituminous pavements, but not until comparatively recent years have they been employed in extensive pavement construction. They have, however, been used to a considerable extent in Europe, and are becoming increasingly popular in America. The emulsions most used are Bitumuls, Colas, Barber, and Headley.

Mixtures of crushed stone or slag with asphalt emulsions may be laid cold as previously described for the cut-back type of cold-laid bituminous mixture. An advantage of the asphalt emulsions is that they can be mixed with, or applied to, crushed aggregate that is cold and wet, whereas when the other types of cold asphalt are used, the aggregate must be at least dry.

MIXTURES USING POWDERED ASPHALT AND FLUXING OIL

36. **Westphalt.**—One of the newer developments in paving mixtures consists in using asphalt in powdered form instead of liquid. Two mixtures of this character are Westphalt and Colprovia.

Westphalt consists of fine-graded aggregate, powdered gilsonite for the bituminous binder, and a soft asphalt for the flux. This mixture is not, strictly speaking, a cold-laid type, but it is mixed and delivered to the job cold and is heated just prior to laying. This heating does not require a regular hot-mix plant, but may be done in any suitable cylinder or pan type of heater or in a concrete mixer equipped with an oil burner. The unusual feature is that the asphalt remains unblended when first combined

with the stone during the mixing process; instead, the materials are blended by the application of heat after the mixing has been completed. The grading of the aggregate is similar to that described for the Topeka mix, and the bitumen content is from 7 to 9 per cent. The depth of the course is $1\frac{1}{2}$ or 2 inches after compaction.

37. **Colprovia.**—A mixture of the Colprovia type is made up in the sheet-asphalt grading, the Topeka grading, or the coarse-graded bituminous-concrete grading. The distinguishing feature is the coating of the aggregate with the flux oil and then with the powdered asphalt. The various sizes of aggregate are batched by weight in the usual manner, and are mixed in a pug-mill or other approved type of mixer, after which the fluxing oil is added and the mixing is continued until all the particles of aggregate are coated. At this stage the powdered asphalt is added and the mixing is continued until the powdered asphalt is evenly distributed throughout the mix. The mixture is then discharged into trucks, transported to the job, and laid cold. The blending of the powdered asphalt and the flux does not start until the mixture is rolled, and the process is not completed until the pavement has been subjected to the kneading action of traffic for several days.

OTHER TYPES OF COLD-LAID BITUMINOUS PAVEMENTS

38. **Macasphalt.**—Another type of cold-laid pavement that has been developed in recent years is known as Macasphalt. This mixture is made in the sheet-asphalt grading and also in both the fine-aggregate and coarse-aggregate grading. The asphalt cement is a blend of hard Cuban asphalt fluxed with a Mexican crude oil. The resulting blend makes a very soft asphalt of about 200 penetration, and no liquefiers or solvents are used. The essential feature of this mixture is the absence of high temperatures during the mixing of the asphalt, it being the theory of the patentee that heating in excess of 300° F. injures the cementing qualities and durability of asphalt cement. The mixture is prepared in a regular mixing plant of the pug-mill type, but the temperature of the aggregate is kept below 150° F., and the asphalt cement is fed into the mixer at a temperature of less than 250° F. If the mixture is to be hauled some distance, or if it is to be stored at the job in piles before being laid, a small amount of water is added to the mix to retard the setting up of the asphalt cement. The methods of laying, raking, and rolling are the same as previously described for bituminous mixtures.

39. **Bituminous-Coated Aggregate, or Precote.**—One of the cold-laid mixtures introduced in recent years is Precote, which consists of aggregate coated with bituminous material by the immersion process before the mixture is placed. The bituminous material may be emulsified asphalt, cut-back asphalt, or cut-back tar. When asphalt emulsion is used, it is generally manufactured on the job, and is heated to a temperature of from 180° to 200° F. when combined with the aggregate. A belt conveyer transports the crushed stone, gravel, or slag from the bins to the dipping vat; carries the aggregate through the bituminous material, allowing the excess emulsion to drain off; and then dumps the coated material into trucks.

A Precote pavement is built in two courses and finished with a seal coat. It is laid on a base course of cement concrete or of compacted gravel or macadam. The binder course is made of aggregate from $2\frac{1}{2}$ to $1\frac{1}{2}$ inches in size, with from 3 to 4 per cent. of bituminous material, and the wearing course is made of aggregate $\frac{3}{4}$ to $\frac{1}{4}$ inch in size with from 5 to 6 per cent. of bituminous material. The binder course and the wearing course are placed and rolled separately in the usual manner. Then a seal coat of emulsified asphalt is broomed over the surface at the rate of $\frac{1}{3}$ gallon per square yard, and this is covered with sand at the rate of about 15 pounds per square yard.

MAINTENANCE OF BITUMINOUS PAVEMENTS

40. **Nature of Maintenance Work.**—The maintenance operations for all the various types of bituminous pavements described in the preceding articles are essentially the same. These operations include filling holes, restoring service cuts, sealing cracks, repairing surface irregularities and disintegrated places, remov-

ing rolls in the surface, and repairing fat spots (that is, parts of the pavement containing too much bituminous material), oily spots, or other areas at which there is a tendency for vehicles to skid excessively in wet weather. Some repairs may involve merely the removal and restoration of a comparatively small portion of the wearing course, whereas others may require the reconstruction of the subgrade and the entire pavement within a comparatively large area.

41. Repairs Involving Subgrade and Base.—If the surface failure has been caused by a base failure, subgrade failure, or gas leakage, the cause of the trouble should be corrected before the surface is restored. The area to be repaired is marked out and the old pavement is removed, the material being first broken up with picks or pneumatic tools to the full depth of the pavement. For service cuts and other work requiring trenches in the subgrade soil, the old base should be cut back for a distance of 4 to 6 inches beyond the sides of the actual trench opening, in order that the new base shall have proper support. The necessary excavation is then made in the subgrade.

When backfilling the trench in the subgrade, care should be taken that the new material is thoroughly compacted during the process by tamping or flushing with water. The material for the new base is then placed and finished at the same elevation as the old base. To avoid obstructing traffic with mixers on the job where a cement-concrete base is being repaired, it has become general practice to use ready-mixed concrete for base replacement. If ordinary concrete is used, the base must be cured for 7 to 10 days, but if high-early-strength concrete is used, the curing period may be reduced to 2 or 3 days.

42. After the base has been properly cured, the sides of the cut in the bituminous surfacing should be cleaned and painted with hot asphalt. Then the binder course—if one is required—and the wearing course are placed in the same manner as for new construction, except that for small areas a power roller cannot be used to compact the binder course, and tampers must be substituted.

The repaired area should blend with the adjoining portions of the pavement so that the patch will not be too conspicuous. Therefore, it is good practice to restore the pavement with the same kinds of materials and to provide the same thickness of courses that were used in the original pavement. However, where a hot-mix bituminous pavement was used originally and no suitable plant is available for preparing the same kind of mixture for the patches, the repairs may be made with cold patching mixes. In this case, the character of the aggregate used should be such that the finished patch will closely resemble the original pavement.

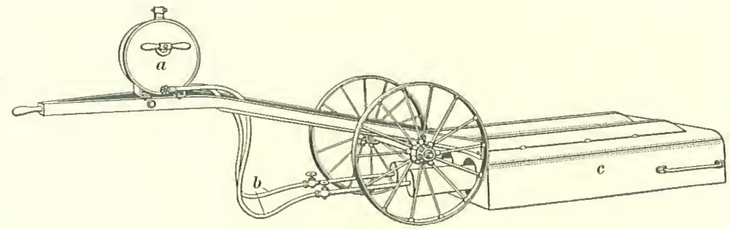


Fig. 8

43. Repairs to Wearing Course.—Where the bituminous wearing course contains comparatively large disintegrated areas or deep holes and ruts, the area to be repaired is marked out and the old surfacing only is removed. The new surfacing is then placed as described in the preceding article.

For minor surface disintegration and surface irregularities, the surface-heater method of repair has been found economical and effective. The equipment used for this work, which is known as a surface heater, has a heater pan of metal which confines intense heat to a small area of pavement. Thus, the upper surface of the pavement is softened and can be scraped off to a depth of from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches. The surface heaters now generally used are of the direct-heating or direct-flame type. A typical heater of this class is illustrated in Fig. 8. The fuel for generating the flame may be gasoline, kerosene, or fuel oil. It is contained in a tank *a* and is led through pipes *b* to burners enclosed by the heater pan *c*. Some engineers prefer the steam or hot-air heaters, but these are very much slower in operation

than the direct-flame types. When a surface heater is used, the surface of the pavement is softened in a very few minutes, and care must be taken to prevent the burning and ruining of the pavement. After the pavement has been softened to the desired depth, the heated material is scraped off with rakes and hoes, and the new material is placed while the pavement is still hot.

44. Where the pavement has become so smooth as to promote skidding, it is good practice to use the surface heater to soften the pavement for a depth of $\frac{1}{2}$ inch and, while the surface is still warm, to roll into it stone chips or screenings so as to produce a non-skid finish. In some areas, oil drippings from motor vehicles produce on the pavement a greasy surface that is exceedingly dangerous to traffic and eventually is destructive to the pavement. The surface heater can be used to soften this oily surface so that it can be scraped off and, if desired, stone chips or screenings may be rolled into the bituminous surfacing to produce a non-skid finish.

BRICK PAVEMENTS

PROPERTIES OF BRICK

MANUFACTURE OF PAVING BRICK

45. The use of bricks for road paving goes back into remote ages. There are evidences of their use in the ancient city of Babylon, and there are roads in Holland in service today which were paved with brick more than 100 years ago. In the United States, the first brick pavements were laid in Charleston, West Virginia, in 1871.

Paving bricks are now made principally from shale, which is excavated, crushed to dust, and mixed with sufficient water to develop plasticity. The raw paste is then compacted and forced through a die, so as to form a continuous ribbon, the dimensions of its cross-section being the length and width of the brick. This ribbon is automatically cut into brick of the proper size by means of wires.

The damp brick are then piled on small cars and taken to the dryer room, where warm air evaporates most of the free water

and leaves the brick hard enough to permit them to be piled in the kilns for burning. In the kiln, the brick are stacked with space around them for the circulation of the hot gases, and sand is placed between the layers to prevent the brick from sticking together. The doorways of the kilns are then closed, the fires are started, and the temperature is slowly raised until, after a period of 5 to 8 days, the brick are brought to a fused state. At

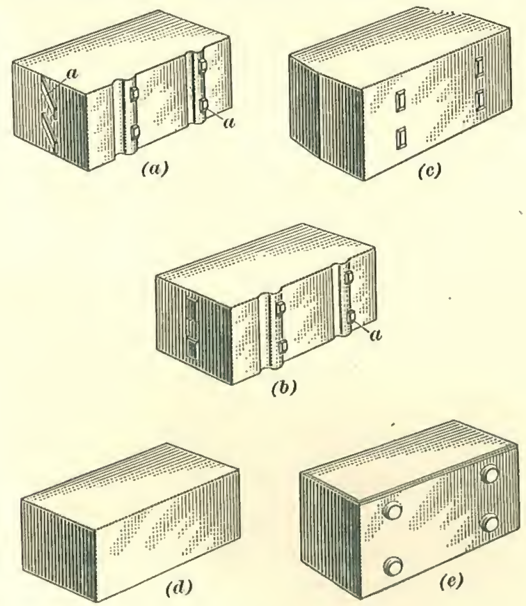


FIG. 9

this point the temperature of the kilns is about 2,000° F. After the brick are thoroughly fused, the kiln is allowed to cool slowly so as to anneal and toughen the brick. This takes from 3 days to 2 weeks, the time depending on the raw material used.

TYPES AND SIZES OF PAVING BRICK

46. **Kinds of Paving Brick.**—The types of paving brick in common use at the present time are illustrated in Fig. 9. The bricks in views (a) and (b) have lugs a on one side and one end. In the case of the brick shown in view (c), one side is provided with lugs and the two ends are beveled. In view (d)

is represented a lugless brick, or one with six plane faces. A repressed lug brick is shown in view (*e*); the lugs are formed on one side by repressing a lugless brick in a special mold. Lug bricks are laid so that plane faces are at the top and bottom. The lugs serve to keep the bricks a sufficient distance apart. Formerly, both wire-cut bricks and vertical-fiber bricks were used extensively, but improvements in the manufacture of vertical-fiber bricks, especially those with lugs, have made this type so popular that wire-cut lug bricks are no longer standard.

47. **Sizes of Brick.**—Prior to 1921, over fifty sizes of paving brick were being manufactured in the United States in order to meet the demands of engineers in different parts of the country. In that year, the Committee on Simplified Practice of the Department of Commerce reduced the number of standard sizes to five, but added a sixth size in 1929. The sizes recommended as standard by this Committee change somewhat from year to year in accordance with the demand, the six sizes in greatest demand being adopted as standard for the season's production. At present, the six sizes that are considered standard are as follows: Vertical-fiber lugless brick, $2\frac{1}{2}$ in.×4 in.×$8\frac{1}{2}$ in. and 3 in.×4 in.×$8\frac{1}{2}$ in.; repressed lug brick, 4 in.×$3\frac{1}{2}$ in.×$8\frac{1}{2}$ in.; and vertical-fiber lug brick, $2\frac{1}{2}$ in.×4 in.×$8\frac{1}{2}$ in., 3 in.×4 in. ×$8\frac{1}{2}$ in., and $3\frac{1}{2}$ in.×4 in.×$8\frac{1}{2}$ in. In each case, the first dimension given is the depth.

TESTING PAVING BRICK

48. Before brick are shipped from the plant, the manufacturer is required to test them in a standard rattler. It is believed that, if the brick are sufficiently hard and tough to pass this test successfully, they are suitable for use in pavements. The rattler, Fig. 10, consists of a revolving metal drum *a* built up of the channel-shaped staves *b* and the heads *c*, which are provided with trunnions. The heads and staves are lined with metal plates which can be readily removed. The drum is supported on a cast-iron frame and is driven by the pulley *d* and the gears *e* and *f*.

In making the test, ten bricks, which have been dried for 3 hours at a temperature of 100° F. and accurately weighed, are

placed in the drum with a standard abrasive charge of cast-iron spheres, and the apparatus is revolved 1,800 times at a uniform rate of not less than $29\frac{1}{2}$ nor more than $30\frac{1}{2}$ revolutions per minute. The spheres forming the abrasive charge are of two sizes, those of the larger size being 3.75 inches in diameter and weighing 7.5 pounds when new, and those of the smaller size being 1.875 inches in diameter and weighing .95 pound when

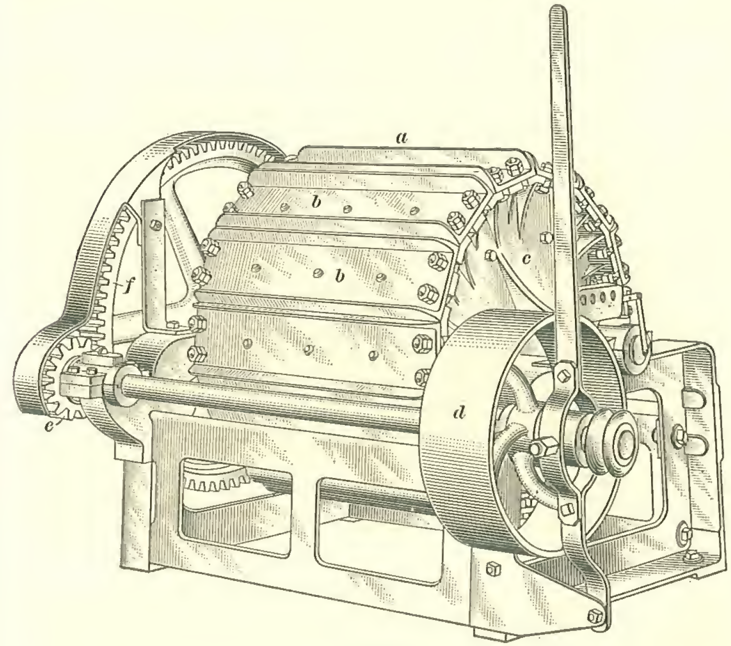


FIG. 10

new. Ten of the large spheres are used and as many of the small ones are added as are required to bring the total weight of the abrasive charge as nearly as possible to 300 pounds. At the end of the test, the brick are removed from the drum and weighed, only pieces weighing at least 1 pound being included, and the per cent. of loss of weight is computed by the formula

$$L=\frac{W_1-W_2}{W_1}\times 100$$

in which L = per cent. of loss;
W_1 = original weight of brick;
W_2 = final weight of brick.

The maximum permissible loss depends on the size of the brick and is as follows:

Size of Brick	Permissible Loss of Weight in Per Cent.
$2\frac{1}{2}'' \times 4'' \times 8\frac{1}{2}''$	26
$3'' \times 3\frac{1}{2}'' \times 8\frac{1}{2}''$	26
$3'' \times 4'' \times 8\frac{1}{2}''$	24
$3\frac{1}{2}'' \times 4'' \times 8\frac{1}{2}''$	22

On the job, the brick are subjected to visual inspection, and those that are broken, chipped, warped, under-burned, or cracked are discarded.

CONSTRUCTION OF BRICK PAVEMENTS

49. Typical Cross-Section.—Two typical cross-sections of brick pavements are shown in Fig. 11. The three essential parts of the pavement are the wearing course *a*, the bedding course *b*, and the base course *c*.

50. Base Course.—The base course for a brick pavement is usually of portland-cement concrete, 6 to 8 inches thick, as shown in Fig. 11 (*a*). In some cases non-rigid bases of gravel, slag, or crushed stone have been used; the base is then generally constructed in two courses, each of which is 4 to 5 inches thick, as indicated in view (*b*).

The edging for both rigid and non-rigid bases is generally of concrete. In the case of a concrete base, shown in view (*a*), the edging at both ends of the pavement may be either integral with the base, as at *d*, or a separate $6'' \times 18''$ curb, as at *e*. Where a non-rigid base is used, as in view (*b*), the concrete edging for both ends either may be a separate $6'' \times 18''$ curb, as at *f*, or may be made 12 inches wide and only deep enough to extend to the top of the bottom course, as at *g*.

51. Bedding Course.—Whatever type of base is used, the brick wearing course is not laid directly on it but on a bedding course of fine material, which is spread on the base for the purpose of taking up any irregularities that may occur in the surface of the base course or any difference in the depths of the individual bricks. The bedding course may consist of sand, granulated slag, limestone screenings, cement and sand, or mastic, which is a mixture of bituminous material and sand. At the present time the mastic, or bituminous-sand, bedding course is growing in favor, although sand or granulated slag is used extensively.

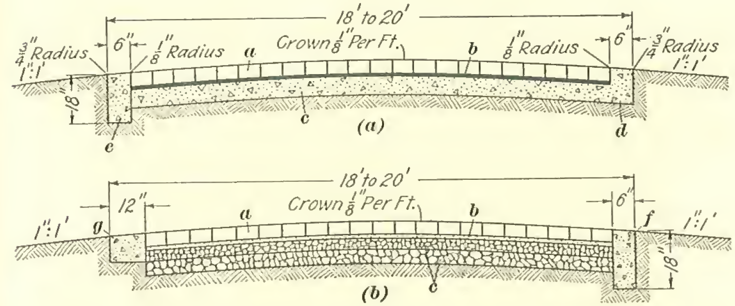


FIG. 11

The mineral aggregate for a bedding course should be clean and free from foreign matter, except a small per cent. of loam. It should be well graded and all of it should pass a $\frac{1}{4}$-inch sieve. The thickness of the bed of sand, slag, or screenings was formerly $1\frac{1}{2}$ to 2 inches but, with the present trend for truer surface finish of the base course, that thickness has been reduced to 1 inch and in some cases to $\frac{3}{4}$ inch. The sand-cement bed is usually made of one part of cement to four parts of sand; the mixture is spread dry on the base course and, after the bricks have been laid and rolled, the pavement is sprinkled with water to hydrate the cement. The bituminous-sand bed is made of sand with about 6 per cent. of light tar or asphaltic oil to hold it together; the materials are usually heated prior to mixing. A sand bed will sometimes flow into the joints and cracks in the base course, causing depressions in the pavement, whereas a mastic bed has

Fig. 12

just enough bitumen in it to hold it together and bridge the cracks.

Whatever type of bedding course is used, it is carefully shaped to a true cross-section by a template extending the entire width of the roadway. The bed is then rolled with a hand roller weighing not less than 10 pounds per inch of width. The roller is usually 36 inches in diameter and 24 inches in width. After the rolling, the template is again used to check the trueness of the bed. The course is then ready for laying the brick.

52. Laying the Brick.—The bricks are carried from piles at the side of the road to the pavers by hand, on pallets, in clamps, or by means of mechanical conveyers; the last-named method is the one now generally used. The conveyer is usually made of rollers mounted on a steel frame, as shown in Fig. 12. The bricklayers, or *droppers,* as they are called, stand on the newly laid brick and face either the bedding course or the curb. When the dropper faces the bedding course, he takes bricks with each hand from the conveyer, which is pulled along in front of him on the bed, and lays them in two or four rows across the road. If he faces toward the curb, the conveyer travels back of him on the brick, and he takes the bricks from the conveyer with one hand, passes them to the other hand, and lays them on the bedding course in four to six rows across the road. A fast dropper can lay from 2,000 to 3,000 bricks per hour, and an extra fast man can lay even more than this.

53. The bricks are usually laid in straight lines, at right angles to the edging or curb. On slight curves, they are laid in radial lines and the space between the lines is increased toward the outside of the curve, a space up to $\frac{1}{2}$ inch in width being permitted. On sharper curves, the bricks are laid in parallel lines except at certain points where adjustments are made by introducing **V**-shaped portions known as *dutchmen.* Two methods of laying the brick at a dutchman, which are employed by the Pennsylvania State Highway Department, are shown in Fig. 13 (a) and (b), respectively. The method illustrated in view (b) is preferable where the angle V is less than about 20°, because no sharp-pointed bricks are required, as would be the

case with the arrangement shown in view (*a*). Where the central angle Δ of the curve is less than about 30° or 35°, one dutchman at the center of the curve is sufficient, as in view (*a*); but, for greater angles, it is necessary to introduce two or more dutchmen, which are so located as to divide the curve into the required number of equal parts. Thus, in view (*b*), two dutchmen are located at the third-points of the curve.

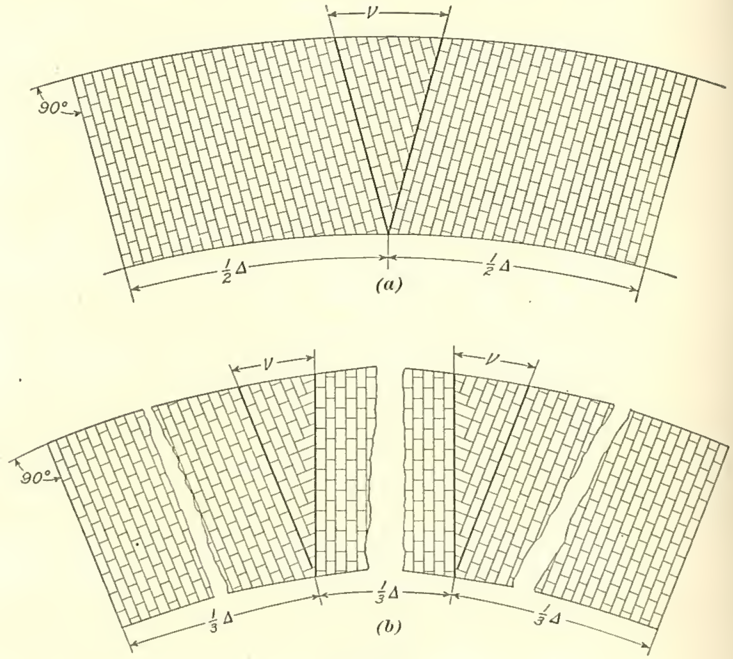


FIG. 13

At an intersection where the traffic from the side road is comparatively light, the brick should be laid across the intersection in the regular manner, that is, in lines that are at right angles to the center line of the main road. However, at an intersection where traffic in both directions is heavy, the brick should be laid diagonally, as shown in Fig. 14.

54. Adjacent rows of brick must break bond. This is accomplished by starting alternate rows with a half brick. No

broken bricks or bats should be used except to finish out a row at a curb or car track or in a dutchman. The brick should be laid so that the better of the two faces is upward. If the bricks have lugs, all the sides with lugs must face in the same direction. Repressed lug hillside brick, which are of the type shown in Fig. 9 (*f*), are placed with the chamfered corner *e* down grade; and wire-cut lug hillside brick, or those of the type shown in

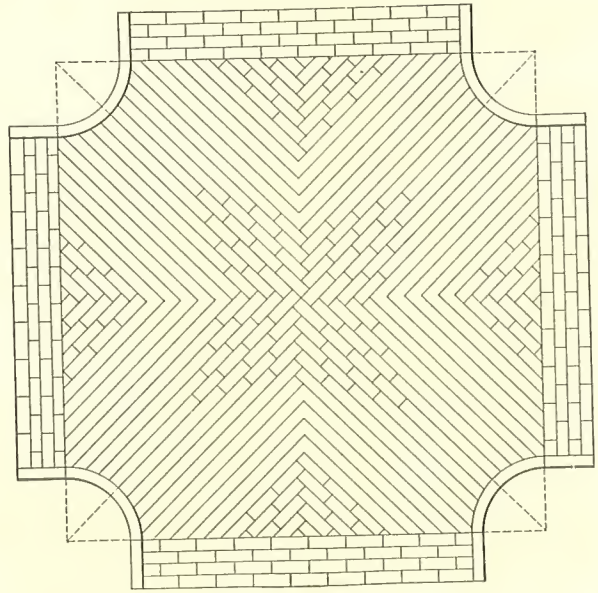


FIG. 14

Fig. 9 (*e*), are laid so that the grooves *d* in the top are across the road, that is, the long dimension of the brick is parallel to the edging of the pavement.

55. Rolling the Brick.—Immediately after the brick have been laid, the surface of the pavement is swept and inspected. Brick that are satisfactory but are not laid with the proper face up are turned over, and defective brick are removed and replaced with acceptable ones. The pavement is then rolled with a power roller weighing approximately 3 tons. The rolling is started along one edge of the pavement and is continued forwards and

backwards parallel to the center line until the center of the road is reached. The rolling for the other half of the pavement is carried out in the same manner, after which the roller is run diagonally across the pavement, first in one direction and next in the direction crossing the first. An inspection of the pavement is then made, all broken or injured brick are removed and replaced with good ones, and the surface is given a final rolling parallel with the center line of the roadway. Portions of the pavement not accessible to mechanical rolling must be tamped with a suitable hand rammer, the blows from which are applied to a plank laid over the brick.

56. **Joint Filler.**—The two materials most commonly used for filling the joints between the bricks are cement grout and bituminous material. The cement grout was formerly the most widely used, but the present practice is in favor of the bituminous filler. The use of plain wire-cut brick probably accounts for the general adoption of the bituminous filler, because, without the wide joints insured by the lugs, it is difficult to make the cement grout go between the bricks. Also, a bituminous filler is flexible and allows expansion and contraction to take place without injury to the pavement. If a cement-grout filler is used and proper allowance is not made for expansion, the pavement is liable to arch itself above the bedding course and become noisy. In some cases the expansion may force the pavement up several feet. Moreover, cracks are frequently formed in the surface of a grout-filled pavement because of contraction. Other advantages of a bituminous filler are that there is not the delay while the material hardens as in the case of cement grout, that repairs for street openings can be made more easily, and that when used on steep grades a pavement with bituminous filler does not become so slippery as one with grout filler. On the other hand, a bituminous filler may become soft in hot weather and, when in this condition, it does not provide sufficient protection for the edges of the bricks, which are liable to be worn off under the action of heavy traffic. Therefore, portland-cement grout is advantageous for special locations, such as street-car tracks, gutters, and parking spaces; but, where this material is employed, expansion

joints should be provided. The use of sand filler is practically limited to temporary construction where it is planned to strengthen the base and relay the pavement at a future time.

57. **Bituminous Filler.**—At the present time asphalt filler is most widely used, although tar is preferred by some engineers. The asphalt used for filler should have a flash point of 392° F.,

Fig. 15

a softening point of 140° to 230° F., and a penetration at 25° C. of 30 to 60. A recent development is to use an asphalt cement impregnated with 25 to 40 per cent. of mineral flour.

The bituminous filler is heated to a temperature not exceeding 392° F. and is applied to the pavement at not less than 350° F. No filler should be applied if the bricks are wet, or if the air temperature is below 50° F. Also, before the filler is applied, the brick should be swept clean. The filler is distributed by means of pressure distributors, wheeled pouring kettles, or hand pouring cans that are conical in shape and are equipped with a rod for regulating the flow of material. The filler is

worked into the joints by means of squeegees which are slowly operated backwards and forwards at an angle with the joints. In Fig. 15 is illustrated the use of a pressure distributor *a* and squeegees *b* in applying the filler. Immediately after the joints are filled, a thin coating of dry stone screenings, sand, or granulated slag is spread on the surface of the pavement and the pavement is then opened to traffic.

58. When bituminous filler is used, an objectionable film of this material covers the whole pavement, and in wet or warm weather this film becomes slippery and dangerous to traffic. Various schemes have been tried to remedy this condition; one that has given excellent results is to paint or spray the surface of the brick pavement with a thin coating of whitewash just prior to using the filler. The whitewash prevents the filler from adhering to the brick and, after the joints have been filled, the excess bituminous material may readily be peeled from the pavement with scrapers.

Glycerin and sodium silicate (water glass) have been used instead of whitewash with good results, but these materials are more costly.

59. Cement-Grout Filler.—The cement-grout filler is made of one part of portland cement and two parts of clean fine sand. All the sand should pass a No. 20 sieve, and not less than 40 per cent. of it should be retained on a No. 50 sieve. The cement and sand are mixed dry, and then sufficient water is added to produce a mixture that will flow into the joints readily but will not separate. The mixing is continued and the ingredients are kept in constant motion until the grout is used. Just prior to applying the grout, the pavement is sprinkled with water, and the grout is then dumped on to the pavement and is immediately swept into the joints until they are filled. After the filler has subsided and before initial set develops, a second application of a thicker grout is swept into the joints and a rubber-edged squeegee is used to complete the filling operation.

Where cement-grout filler is used, expansion joints must be provided along the curb and around all obstructions in the street.

The premolded expansion joint $\frac{3}{4}$ inch wide is the type most commonly used. This premolded material is placed when the brick are laid and is so arranged that after the pavement is rolled the joint material is flush with the top of the pavement. After the grout filler has taken its initial set, it is cured by covering the pavement with sand or loam, which is kept moist by sprinkling for at least 10 days. The pavement is not opened to traffic until the end of this curing period.

MAINTENANCE OF BRICK PAVEMENTS

60. The maintenance of brick pavements consists in replacing poor bricks, refilling joints, repairing areas that have failed on account of subgrade or base weakness, and repairing and restoring the pavement at service cuts. The procedure in restoring a brick pavement over a service cut is the same as previously described for bituminous surfaces up to the placing and curing of the concrete base. After the base has properly cured, the cushion course is placed and the bricks are laid, the joints are filled, and the surface is rolled in the same manner as for a new brick pavement. Care should be taken to use bricks of the same color and shape as were used in the original pavement and, to avoid an unsightly patch, the same type of filler should be employed.

For ordinary repairs other than service cuts, the area needing attention is marked out and the bricks are removed and cleaned. The base should then be cleaned, and all failures repaired. If the base has failed because of inadequate subgrade support, the subgrade should be strengthened and drain tile used if necessary. Upon the clean base course, the cushion course is placed and then the bricks are relaid, the joints are filled, and the pavement is rolled.

61. Where the whole brick pavement for large areas has become badly rutted and uneven, the bricks may sometimes be taken up and laid on a new face, or the old brick surface may be covered with concrete or with a mixed bituminous type of pavement. When a bituminous mixture is used on top of an old brick surface, the depressions in the old surface should be filled

up with bituminous base material prior to placing the surface course. If this is not done, the bituminous mixture will compress unequally and depressions in the new surface will occur over the depressions in the old pavement.

BLOCK PAVEMENTS

ASPHALT-BLOCK PAVEMENTS

MANUFACTURE OF ASPHALT BLOCKS

62. **Composition of Asphalt Blocks.**—The use of asphalt blocks dates back to about 1869, when they were laid in the city of San Francisco. The asphalt blocks are made of a properly proportioned mixture of crushed rock, inorganic dust, and asphalt cement, which is heated and molded into uniform blocks under heavy pressure. The blocks are made in several sizes, but the usual size is 12 in.×5 in.×2 in. Because of the special machinery required to compress the blocks, they are manufactured in large permanent plants where they are stored until required or are made on order and shipped directly to the job.

The coarse aggregate for asphalt blocks is usually obtained by crushing some hard rock, such as trap, dolomitic limestone, or copper conglomerate. The particles should be as nearly cubical as possible and of such size that 97 per cent., by weight, will pass a $\frac{1}{4}$-inch screen. The material should have a percentage of wear of not more than 5, and the crushed aggregate must be thoroughly clean. The inorganic dust may be ground limestone, portland cement, clay, shale, or marl of such size that at least 90 per cent. will pass a 30-mesh sieve and not less than 50 per cent. will pass a 200-mesh sieve. A sufficient amount of this filler should be used to give the minimum percentage of voids in the block and to provide a medium for absorbing the asphalt cement. The asphalt cement is somewhat harder than that used for other types of asphalt pavements. The usual requirements are a penetration from 10 to 45 and a ductility of not less than 5 centimeters.

63. **Asphalt-Block Plants.**—A plant for the manufacture of asphalt blocks should be equipped to perform the following

operations: Crushing the coarse aggregate; grinding the inorganic dust; handling the asphalt cement; proportioning, heating, and mixing the ingredients; pressing and cooling the blocks; and testing and analyzing the raw materials and the finished blocks. Coarse aggregate that is suitable for use without crushing may be available, and inorganic dust of the proper fineness may be purchased. However, it is usually preferable to install crushing and grinding machinery at the plant and to manufacture the coarse aggregate and dust.

The inorganic dust is carried from the grinding mill on a belt and is stored cold in bins until it is used in the mixer. As the coarse aggregate is received from the crushing rolls, it is passed through a $\frac{1}{4}$-inch screen and is stored in bins from which it is taken to a heater. The hot material that comes from the heater is elevated to hot-storage bins, which are provided with suitable recording thermometers, and is then ready for use at the mixer as required. The asphalt is melted by the application of heat, and may be refined or fluxed to the desired consistency in two or more tanks, the heat being supplied by direct fire or preferably by steam coils. The hot asphalt is agitated by means of steam or air jets escaping from perforated pipes near the bottoms of the tanks, and is maintained at the proper temperature until required in the mix.

The properly prepared ingredients are delivered to the mixer platform, where they are carefully proportioned before being fed into the mixer. Each batch is mixed for the same length of time, the period of mixing being determined by a sand glass. The mixture is then placed in a mold and subjected to a pressure of about 4,000 pounds per square inch on a 5 in.×12 in. face. The blocks are finally passed under cooling water.

The raw ingredients are subjected to the various tests that are generally made on mineral aggregate and bituminous materials. In addition, the blocks should be tested at the plant for specific gravity, hardness, per cent. of bitumen, grading of mineral aggregate, water absorption, and abrasion.

64. **Requirements for Blocks.**—Asphalt blocks should be uniform in texture and composition, straight and true to form,

and free from warp, wind, or rounded or imperfectly formed edges. The planes of the opposite sides should be parallel. Any variation of over $\frac{1}{4}$ inch in length or $\frac{1}{8}$ inch in width or depth from the specified sizes should be sufficient cause for rejection. The blocks should have a specific gravity of not less than 2.30 to 2.45, the limit depending on the specific gravity of the mineral aggregate.

The average absorption for four blocks should not exceed .5 per cent., by weight, when tested in the following manner: The blocks are cleaned of loose particles and are carefully weighed. They are next subjected to a vacuum of 22 inches for 1 hour at room temperature, and then, while the vacuum is maintained, water is admitted to the vessel until the blocks are completely immersed. After this the vacuum is relieved, and the water pressure is carried up to 100 pounds per square inch and is there maintained for 1 hour. The blocks are then removed from the vessel, all their surface water is mopped off, and they are carefully reweighed. From the data obtained, the per cent. of absorption is calculated by the formula

$$A=\frac{W_2-W_1}{W_1}\times 100$$

in which A = per cent. of absorption;
W_2 = final weight of wet block;
W_1 = initial weight of block.

The composition of asphalt blocks, based on the weight of the entire block mixture, should conform to the following requirements:

Retained on $\frac{1}{4}$-inch screen........not more than 3 per cent.
Passing a $\frac{1}{4}$-inch screen and retained
on a 20-mesh sieve ....35 to 60 per cent.
Passing a 20-mesh and retained on a
100-mesh sieve ....15 to 30 per cent.
Passing a 100-mesh sieve..........20 to 40 per cent.
Passing a 200-mesh sieve ....not less than 15 per cent.
Bitumen ....6.5 to 10 per cent.

LAYING ASPHALT BLOCKS

65. Preparation of Mortar Bed.—The cross-section of an asphalt-block pavement is similar to that of a brick pavement. Asphalt blocks are usually laid on a cement-concrete foundation, but an old macadam, brick, or stone-block pavement may sometimes be used to advantage as a base for the new road. On the prepared base is placed a mortar bed, about $\frac{1}{2}$ inch thick, which is composed of one part of cement and three or four parts of sand. The mortar for the bed is spread evenly over the base and is struck off to a true surface by means of templates. Steel strips $\frac{3}{16}$ or $\frac{1}{4}$ inch thick are embedded in the mortar so that their top surfaces conform to the crown of the pavement and are just the depth of the blocks below the finished surface. These strips are set in parallel rows 10 to 16 feet apart, the distance depending on the length of the steel straightedge used on the job. The steel straightedge, or *strike board,* is drawn on two of the steel strips so as to strike off the mortar bed to a true and even surface. After the mortar has been struck off, the steel strips are removed and the spaces are carefully filled with mortar.

66. Method of Laying Blocks.—The asphalt blocks are immediately laid on the freshly placed mortar bed in much the same manner as bricks are laid, the 2-inch dimension being the depth and the 5-inch dimension running lengthwise of the pavement. Three rows of blocks are laid across the pavement at one time. The joints in adjoining rows are broken by starting the first row with a whole block, the second row with a piece of block 8 inches long, and the third row with a piece 4 inches long. Whole blocks are used for the entire width of the pavement, except for the necessary closers at the far edge. These closers should be at least 3 inches long and should be placed before the mortar has begun to set. The joints between the blocks are kept as tight as possible and, while the blocks are being laid, each block is bedded solidly on the mortar and is kept in alinement by tamping it across the middle with another block.

As the paver sets the blocks in three rows, additional blocks for the next three rows are placed by a helper in piles of three

at intervals of 12 inches. The pavers stand on the blocks already in place and not on the mortar bed. Where there is a bulge in alinement, a board is placed against the row of blocks last laid and is struck with a light sledge hammer. Occasionally, it may be necessary to adjust the alinement by inserting the blade of an ax between two rows of blocks and wedging the blocks apart.

67. **Filling Joints.**—The most satisfactory filler for the joints is emulsified asphalt that contains about 55 to 60 per cent. of asphalt and 40 to 45 per cent. of water. This filler is applied cold by means of a pouring pot. A gallon of such material will cover about 3 square yards of pavement with 5″×12″×2″ blocks. The surface of the pavement is first swept thoroughly, an area large enough to use up the contents of the pouring pot is then sprinkled with fresh water, and the emulsion is spread evenly over that area. The emulsion is then wiped into the joints by means of squeegees until all surplus liquid is removed from the top surfaces of the blocks. Before the emulsion has set, the surface should be sprinkled with a thin layer of clean, fine sand that is broomed well into the joints and evenly over the surface. The pavement is kept closed to traffic for about 7 days if ordinary portland cement is used in the mortar bed and for about 2 days if high-early-strength cement is used.

68. The joints are sometimes filled with sand in the following manner: After the blocks in a section of pavement have been properly bedded, the surface is covered with sand. As much of the sand as possible is swept into the joints, and the excess is allowed to remain to be ground into the joints by traffic. On some jobs, an asphalt seal coat and a blotter of fine sand or stone screenings have been applied.

69. **Non-Skid Construction.**—The so-called non-skid construction with asphalt blocks has been designed primarily to reduce skidding on curves or fairly steep grades and at intersections or other danger points. In this construction, the blocks in each row are laid with tight joints, and adjoining rows are kept $\frac{3}{8}$ inch apart by means of spacing strips $\frac{3}{8}$ inch wide and 2 inches deep. After the pavement is laid, the spacing strips

between the rows are removed and the spaces thus left are filled with free-flowing grout, containing 1 part of portland cement to $1\frac{1}{2}$ parts of sand. The grout is poured over the pavement surface and is brushed well into the joints with a long-handled push-broom until the joints are filled almost to the top. After the filler has taken an initial set, or in about 30 minutes, it is scraped out from each transverse joint to form a recess about $\frac{1}{2}$ inch deep. Provision for draining the recesses should be made by laying along each curb and parallel with it a single row of blocks the top surface of which is $\frac{1}{2}$ inch below the surface of the adjoining pavement. The grout should be cured by wetting the surface each morning and afternoon.

STONE-BLOCK PAVEMENTS

70. **General Remarks.**—Stone blocks have been used for street paving for over 2,000 years. Their present use in the United States is chiefly in pavements that are subjected to espe-

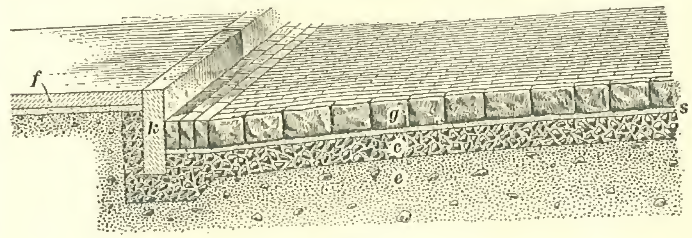


FIG. 16

cially severe traffic conditions, as around dock and warehouse districts, on steep hillsides, and where heavy horse-drawn, steel-tired vehicles predominate. Granite is the stone mostly used for stone blocks, but sandstone and trap rock are used to a considerable extent. Stone blocks are made in several nominal sizes, but even on the same job the size will vary somewhat on account of the difficulty of splitting the stone accurately. Generally, the length of the blocks ranges from 6 to 12 inches, the width from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches, and the depth from 4 to 5 inches.

71. **Features of Construction.**—In Fig. 16 is shown a perspective view of part of a roadway paved with granite blocks

that are laid on a foundation of portland-cement concrete and a bedding course of sand or sand and cement. Here, *e* is the natural earth subgrade; *c*, the concrete base; *s*, the bedding course; and *g*, the course of granite blocks. The curb *k* and the sidewalk *f* are also shown in the illustration.

Stone block was formerly laid on the natural subgrade or on a base of crushed stone, gravel, or sand, but at the present time a cement-concrete base course 8 to 10 inches thick is the prevailing practice. The bedding course for stone blocks is sand or sand-cement and is usually from 1 to 2 inches in thickness. When the sand-cement bed is used, the materials are mixed and laid dry in the proportions of one part of cement to three or four parts of sand. After the blocks have been laid, the pavement is sprinkled to hydrate the cement. The blocks are laid on the bedding course with their longest dimension at right angles to the curb, the paver selecting blocks of nearly the same width for a whole course. The blocks are laid in close contact so that the joints will be narrow. In case the depth of the block is slightly excessive, the paver scoops out some of the sand bed with his flat-bladed paving hammer in order to make the top surface uniform. When the block is in place, it is gently tapped with the hammer to bed it firmly into the sand; and, after a section of pavement has been laid, the blocks are rammed into place by heavy rammers or tampers. The tamping is very important, because the smoothness of the pavement will depend on the skill used in this operation.

72. Various materials, including cement grout, tar, pitch, asphalt, and mastic, are commonly employed for filling the joints between stone blocks. Cement-grout filler is made and applied as previously described for brick paving, the mixture containing one part of cement and one or two parts of sand, and having the consistency of thin cream. Tar, pitch, or asphalt fillers are applied hot and are squeegeed into the joints. The mastic filler is made of one part of sand and one part of asphalt; both materials are heated to a temperature of about 300° F. and are then mixed in a mixer with paddles. The mixture is flushed into the joints with squeegees.

In order to give the cement-sand bed a chance to set up and thus hold the blocks firmly, it is customary to keep traffic off the pavement for at least 10 days after the blocks are laid. During this period the pavement is sprinkled two or three times daily.

73. **Durax Block.**—Durax stone block, or Kleinpflaster, is made of stone cubes 3 or 4 inches wide. These cubes can be made by machine and are therefore somewhat cheaper than the

Fig. 17

regular large-size stone block. The blocks are not laid in straight rows, but in concentric circular segments as shown in Fig. 17. The usual curvature is such that for a chord of 4 feet the middle ordinate is about 12 inches. This method of laying the blocks eliminates joints parallel to the line of traffic and tends to make a smoother riding pavement; besides, it is pleasing to the eye. The bedding course and filler are the same as previously described for regular stone-block pavements, but the compression is applied by means of a 5-ton roller.

74. Recut Stone Blocks.—In many cities where old stone-block paving has become too rough for modern traffic, the blocks have been taken up, split into cubes, and relaid so that a fresh face is uppermost. Such blocks are extensively used for street-car-track paving and sometimes for Durax pavements.

WOOD-BLOCK PAVEMENTS

75. Manufacture of Wood Blocks.—Wood paving blocks are made of southern pine, tamarack, Norway pine, hemlock, and Douglas fir. The blocks are made in several sizes, but the most popular sizes are 3 to $3\frac{1}{2}$ inches deep, $2\frac{1}{2}$ to 4 inches wide, and 8 to 10 inches long. It is important that the blocks be free from large knots, rot, or shakes, and it is usually specified that not less than 70 per cent. of the block shall be heartwood.

Wood blocks are treated with creosote oil and tar to preserve the wood and to prevent the absorption of water which would cause serious swelling. In past years, many wood-block pavements have buckled badly on account of the swelling of the blocks in wet weather, but this is prevented on modern pavements by better creosoting and adequate expansion joints. The blocks are cut from seasoned timber by gang saws, and are steamed in the creosoting cylinder for several hours. Then a vacuum is created in the cylinder for about 1 hour and, while the vacuum still exists, preservative oil at a temperature of about 200° F. is run into the cylinder until it is filled. Finally, pressure is gradually applied until the wood has absorbed the required amount of oil.

76. Construction of Wood-Block Pavement.—The only material now used as a foundation for a wood-block pavement is cement concrete. On the base is placed either a bedding course of cement mortar or a thin cushion of bituminous mastic. At the present time, the mastic is more popular than the mortar, as it is more impervious to moisture and prevents excessive swelling of the wood blocks. The bituminous cushion, which is about $\frac{1}{2}$ inch thick, is made by applying hot tar or asphalt and blotting it with sand. The blocks are laid on this cushion in much the same manner as previously described for bricks, but care must be taken to provide an expansion joint between the rows. This may be accomplished by employing blocks with suitable lugs. If blocks with lugs are not used, an expansion joint is made by placing a narrow strip of corrugated paper between the rows. It is also customary to provide a 1-inch transverse expansion joint every 50 feet and a longitudinal expansion joint at each curb or gutter. The manner in which wood blocks are laid in the pavement is illustrated in Fig. 18.

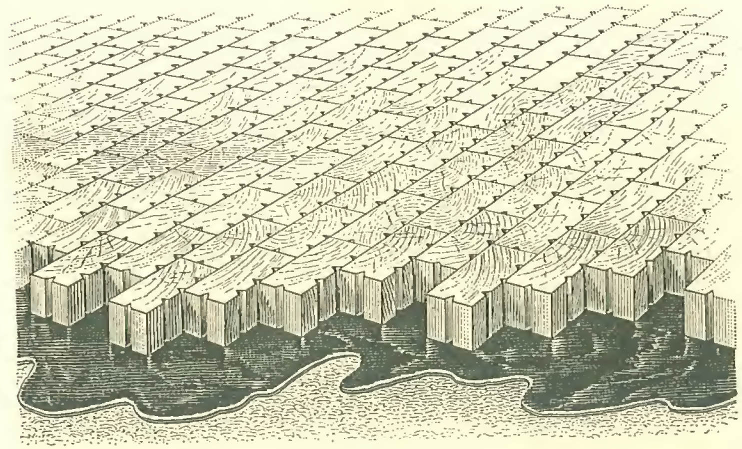


Fig. 18

A bituminous filler is most widely used at present for wood-block pavements, although sand is preferred by some engineers. The bituminous filler is applied hot and is worked into the joints with brooms and squeegees. The pavement is then covered with sand for a few days, after which the excess sand is removed and the pavement is opened to traffic. In wet weather the pavement tends to become somewhat slippery and a light sanding is usually applied at such times until traffic has ground some of the sand into the surfaces of the blocks.

RUBBER PAVING BLOCKS

77. Rubber paving block has been used to a limited extent in Europe and on a few experimental sections in the United States. The cost of this type of paving is considerable and some difficulty has been met in devising a practical method of attach-

ing the rubber to the base material. The blocks are usually made with a 1-inch tread of rubber attached to a foundation block of wood or brick. The size of the block is approximately the same as the usual paving brick, although some blocks are nearly a foot long. The advantages claimed for rubber paving are that it is noiseless, non-skid, and very enduring. It is also expected to do away with the vibration which is transmitted to adjacent buildings by the hard types of paving. This type of block is always placed on a rigid base of cement concrete.

SIDEWALKS, CURBS, AND GUTTERS FOR STREETS

SIDEWALKS

78. Use of Paved Sidewalks.—Sidewalks are provided for the accommodation of pedestrians on city and village streets and also in parks. On business thoroughfares, the entire space between the curb and the property line on both sides of the street is occupied by a paved sidewalk. On residential streets, a paved walk only 4 to 6 feet wide is provided on each side of the street, and the rest of the space between the curb and the property line is planted with grass and rows of trees. There is no rigid rule for the location of the paved walks on such streets; a layout like that shown in Fig. 19 gives a pleasing appearance, but the walk may also be laid next to the property line or adjacent to the curb. In parks, the sidewalks may be either alongside the driveways or not. No walkways are necessary on roads in open country, but in suburban districts narrow footpaths are often provided alongside the roadway.

The materials commonly used for sidewalks are the following: portland-cement concrete, stone slabs or flags, small stone blocks or setts, brick, tile, asphalt mastic, gravel, cinders, and tar and asphaltic concrete.

79. Heights of Sidewalks.—On business thoroughfares, the sidewalk edge that is nearer to the curb is always placed at the same grade as the curb, which is generally at or near the street grade. The edge adjacent to the building line is elevated somewhat above the curb in order to provide a slight inclination

toward the gutter for drainage. The lateral slope should be uniform from the building line to the curb and is usually $\frac{1}{8}$ to $\frac{1}{4}$ inch per foot.

As shown at the right-hand side in Fig. 19, the sidewalks of residence streets are usually placed approximately at the grade of the curb whenever the natural cross-section of the street is sufficiently level for this to be done without inconvenience or disadvantage to adjoining property. It is decidedly the best practice, especially in the case of paved streets, to put the sidewalks either at the grade of the curb or a certain small distance,

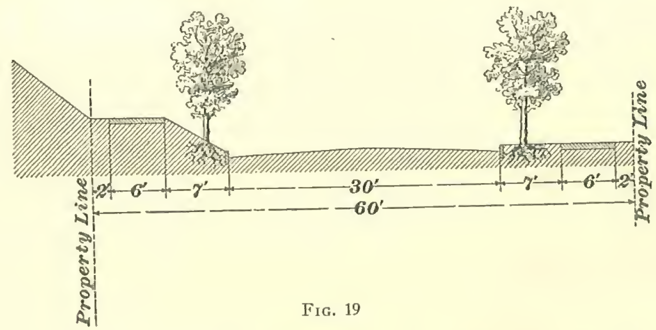


Fig. 19

say 3 or 4 inches, above that grade. In many cities, however, the elevations of the sidewalks on residence streets are varied materially from the curb grades whenever the adjoining property is thereby better accommodated. Thus, on the left-hand side in Fig. 19, the sidewalk is elevated considerably above the curb in order to accommodate the relatively high position of the adjacent property. Such variation should be avoided as much as possible, because the appearance of the street is much more pleasing when both sidewalks are placed near the street grade. Except in cases where the sidewalk is considerably above the grade of the curb, the entire portion of the street between the property line and the curb should have a uniform lateral slope of $\frac{1}{8}$ to $\frac{1}{2}$ inch per foot, depending on the nature of the surface.

80. Sidewalks of Portland-Cement Concrete.—A concrete sidewalk may be considered a miniature concrete pavement in most respects. Therefore, the essential requirements for a con-

crete sidewalk, as for a concrete pavement, are a well-drained foundation bed, good materials, and careful workmanship.

The recommended thickness of the sidewalk slab is 5 inches for residential districts and 6 inches for business districts. Concrete sidewalks should be laid in blocks or slabs entirely separated from each other by joints. The width or length of each slab should not exceed 6 feet. The joints should preferably be made by means of metal separation plates $\frac{1}{8}$ to $\frac{3}{16}$ inch thick, cut to the cross-section of the walk, and provided at each end with a lug that fits into a notch in the forms. Sometimes the joints are made by cutting entirely through the concrete with a spade-like tool, and then rounding the edges with an edger. It is not good practice to separate the blocks only partly by making shallow grooves in the surface, as ugly cracks will surely form.

At intervals of not more than 50 feet along the walk there should be provided $\frac{1}{2}$-inch expansion joints filled with bitumen. Also, an expansion joint 1 or 2 inches wide should be constructed between the sidewalk and the curb where the two adjoin. A $\frac{1}{2}$-inch expansion joint should be inserted all around the intersection of two sidewalks and between a sidewalk and a drive or a private walk.

81. Under ordinary conditions, concrete sidewalks may be laid directly on the soil without special preparation of the foundation bed. However, in the case of subgrades that are continually wet, special treatment is required to insure a well-drained foundation bed. In such cases it is often sufficient to lay a line of tile parallel to the walk on the up-hill side, thereby intercepting seepage and keeping the subgrade dry. Where such tiling is impracticable and special provision for drainage is necessary, it is advisable to place a 4-inch subbase of cinders, gravel, or a similar material, and provide a drain for carrying away the water that collects in that material.

Concrete sidewalks may be constructed by either the one-course or the two-course method. The one-course method produces a stronger and more durable walk and is therefore more desirable. A blunder frequently made in sidewalk construction is to place a wearing surface of extra-rich mixture troweled to

a glossy surface. Such finish wears no better than the surface of a one-course walk and becomes exceedingly slippery in frosty weather.

The finished walk must be kept moist for several days until hardened, and should preferably be kept covered with boards, tarpaulins, or tar paper to protect it against injury.

The proportions recommended for one-course sidewalk construction are 1:2:3, the maximum size of the coarse aggregate being 1 inch. In two-course construction, a 1:$2\frac{1}{2}$:4 concrete should be used for the base and a 1:2 mortar for the top, the size of the coarse aggregate for the base not exceeding $1\frac{1}{2}$ inches. Granite or trap rock is best for one-course sidewalk work, but hard limestone and clean gravel are frequently used with good results. Coloring material may be incorporated in the concrete mixture so as to obtain a variety of colors and thus improve the appearance of the walk.

82. **Stone Sidewalks.**—Sidewalks of stone flagging are frequently used in business districts and are also employed in residential districts in localities where suitable material is readily obtainable. Granite and a species of sandstone known as bluestone are the stones generally used for sidewalk flagging. Granite is very durable, but wears smooth and becomes slippery. However, it may be easily roughened by means of a tool called a tooth ax. When sandstone is of compact texture so that it absorbs comparatively little water, it is generally quite satisfactory.

The thickness of stone flagging should be uniform and not less than 3 inches. Each flagstone should have a top area of at least 10 square feet, except where the stone must be cut to fit around the head of a catch basin or manhole. The flagging should be firmly bedded on a foundation of sand or gritty gravel, and the joints between the flagstones should be filled with cement mortar.

In many cities in Europe, sidewalks are constructed of small stone setts, which are laid in arcs of circles, as shown in Fig. 17 for Kleinpflaster, or in fancy designs. Also, the stones may be of different colors to produce a more pleasing appearance.

83. Brick Sidewalks.—Bricks are suitable for sidewalks in residential and suburban districts of cities and on the main streets of small towns. Either paving brick or good hard-burned building brick is used. Best results are obtained when the bricks are supported on a cement-concrete foundation 4 inches thick, but a foundation course of good gravel or cinders 6 inches thick is sometimes used. A bedding course of sand 1 inch in depth is placed over the foundation, and the brick surface is constructed in practically the same way as a brick roadway pavement.

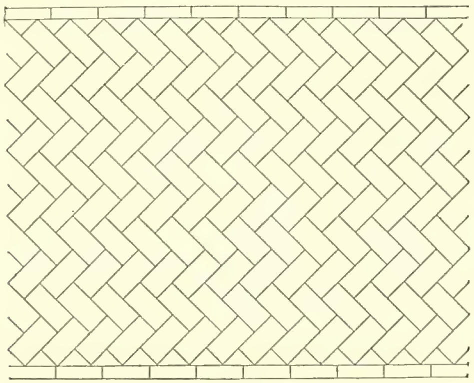


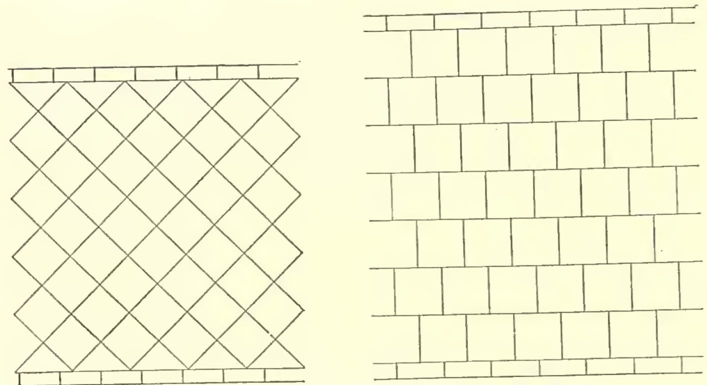
FIG. 20

The bricks may be laid in rows with their longest dimensions either at right angles to the curb or diagonally, or they may be arranged in herring-bone fashion, as shown in Fig. 20. Here, a curbing consisting of bricks laid lengthwise is shown along each edge of the sidewalk, and small triangular-shaped pieces are required to fill the spaces between the diagonal bricks and the curbing. These triangular pieces are cut from whole bricks by the paver. The joints in brick sidewalks are usually filled with a bituminous material.

84. Tile Sidewalks.—Tiles for use in sidewalk construction are usually made of burned clay, but compressed-asphalt tiles are used to some extent. The exposed surfaces of the tiles are square. Two methods of laying the tiles are shown in Fig. 21

(*a*) and (*b*). The details of construction are almost identical with those for brick walks.

85. Asphalt-Mastic Sidewalks.—In France, a mastic prepared from a combination of natural rock asphalt and a refined asphalt fluxed with an asphaltic oil is used as a surfacing for sidewalks. A cement-concrete base about 4 inches thick is laid first and this is coated with a layer of cement mortar $\frac{1}{2}$ to 1 inch in thickness. The mastic is then placed to a thickness of about 1 inch and, while this material is still warm, gravel is spread thinly over the surface and lightly rolled into the mastic.



(*a*) (*b*)

FIG. 21

86. Gravel Walks.—Walks of gravel are widely used in suburban districts, parks, and pleasure grounds. Where the subgrade is good, a layer of gravel 3 or 4 inches thick can be laid directly on the soil. If the subgrade material is poor, it is excavated to a depth of as much as 8 inches and the space is refilled with crushed stone, clinker, or screened gravel of large size. The wearing course then consists of a layer of fine gravel or coarse sand $\frac{1}{4}$ to $\frac{1}{2}$ inch thick.

87. Cinder Walks.—In outlying districts, it is often desirable to build cheap temporary walks. For this purpose a layer of cinders 6 to 12 inches thick gives fairly satisfactory results. The cinders are placed in layers, the material in each layer being

wetted and tamped or rolled thoroughly. Such a walk can later be used as a base for a more substantial wearing surface.

88. Walks of Bituminous Concrete.—Walks of tar concrete are usually built in two or more courses, each of which is thoroughly tamped and rolled. The base course is from 2 to 4 inches thick and consists of coarse gravel and tar. The wearing course is 1 inch thick and is composed of coarse sand and tar. Between the base and wearing courses, there is sometimes a 1-inch binder course of tar and screened gravel up to 1 inch in size. Usually the top surface is sprinkled with fine sand or portland cement before it is rolled.

Sidewalks of sheet asphalt, asphaltic concrete, and cold-laid bituminous mixtures have also been constructed.

CURBS AND GUTTERS

89. Materials and Forms of Curbs.—On city streets, it is customary to provide curbs at the edges of the roadway, as shown in Fig. 16, where *k* is the curb and *f* is the sidewalk. The curb may be of concrete or of granite, sandstone, or limestone. The form and dimensions of curbstones vary considerably in different localities, and are not subject to rigid regulations.

90. Stone Curbs.—Curbs of hard natural stones are strong and durable, and are generally preferred where wheels of heavily loaded trucks are constantly striking against the curb. Curbstones vary from 4 to 12 inches in width, from 8 to 24 inches in depth, and from 3 to 8 feet in length. The front face of the curb should be hammer-dressed and given a slight batter to a depth somewhat greater than that exposed above the roadway pavement. Also, where the sidewalk extends to the curbing, the back of the curb should be dressed to a sufficient depth to allow the sidewalk pavement to fit closely against it. The ends of the stones should be dressed square throughout their entire depth, so that they can be laid with close joints. The top surface of the curb should be dressed to a bevel corresponding to the slope of the adjoining sidewalk.

Curbstones should be set true to line and grade, and should be bedded firmly on a solid foundation so that they will keep their

proper positions. The stones are commonly laid on a well-compacted sand base, but it is much better to provide a base of concrete, broken stone, or gravel that is carried well up around the curb. Where the roadway is provided with a concrete foundation, the base for the curb should be made continuous with that for the pavement.

91. Concrete Curbs.—Concrete has been used for curbs for many years and in constantly increasing quantities, especially for streets in residential districts, parkways, and private drives. For such purposes, concrete combines good appearance with ample strength and reasonable cost. For streets with heavy trucking, the concrete may be strengthened by embedding a metal protector or a steel angle in the exposed corner of the curb, but where the face of the curb is curved or sloped so that wheels of vehicles strike the face of the curb and not the top edge, such protection bars are not necessary.

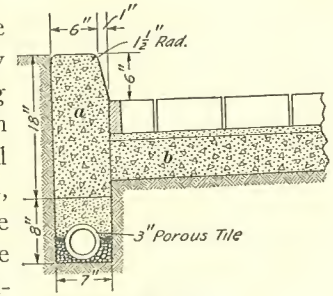


Fig. 22

92. Types of Concrete Curbs.—There are three general types of concrete curbs, namely, the separate curb, the combined curb and gutter, and the integral curb. One type of separate concrete curb is shown in Fig. 22, in which *a* is the curb and *b* is

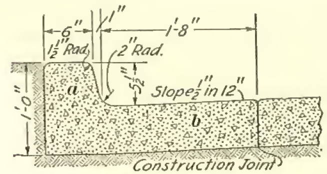


Fig. 23

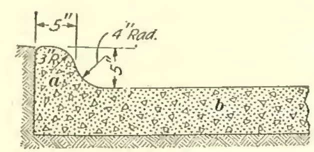


Fig. 24

the concrete foundation for a brick wearing surface. The drain tile under the curb is required only in soils that contain free water.

In the combined curb and gutter, illustrated in Fig. 23, the curb *a* and the gutter *b* are cast in one piece. This construction

is often used on unpaved streets and for streets with wearing courses other than concrete, especially those with bituminous surfaces. Its use with concrete pavements is steadily diminishing, because it forms a longitudinal joint where none is needed and where the joint is subjected to heavy wear from wheels of vehicles.

The integral curb illustrated in Fig. 24 represents the most economical and practical type of curb construction. Here, the curb *a* is built monolithically with the concrete pavement *b*. Integral curbs are advantageous because, in addition to performing the usual functions of a curb, they act as thickened edges for the concrete pavement and thereby provide strength where it is needed; besides, they eliminate the unnecessary longitudinal joint between the curb and gutter. In streets that are surfaced with materials other than concrete, integral curbs are sometimes provided by pouring the curb monolithically with the concrete base.

93. **Separate Curbs.**—Separate curbs are often built after the pavement is completed, because it is easier to finish the pavement slab with a form at each side than with a comparatively high curb. The curb is generally divided into sections 6 to 8 feet long by means of joints extending entirely through the concrete. Also, the curb and the slab should preferably be tied together by means of short bars, in order to prevent the opening of the joint between them; two bars for each section will generally suffice. Expansion joints should be provided in the curb at intervals of not more than 50 feet, at the ends of curves for street corners, and opposite the joints in the pavement. Separate curbs are sometimes constructed by setting precast sections which are usually held in line and grade by means of dowels.

94. **Combined Curb and Gutter.**—A combined curb and gutter should be built in sections 8 to 10 feet in length and should also be provided with expansion joints as for separate curbs. When used with concrete pavements, the curb and gutter is sometimes tied to the pavement by means of $\frac{1}{2}$-inch diameter dowels, 24 inches long and spaced about 18 inches on centers.

95. **Integral Curb.**—When a street is curbed and paved with concrete, the curb can be readily built as a monolithic portion of the pavement. Where reinforcement is used in a pavement having integral curbs, the sheets of steel are extended into the curb in order to anchor it more effectively. The curb is sometimes reinforced by means of one $\frac{1}{2}$-inch bar placed 2 inches from the top and one placed near the bottom; the purpose of this reinforcement is to prevent the spreading of cracks. The only joints required in the curb are the transverse joints extending from the pavement slab, but these joints should be twice as wide in the curb as in the slab.

96. **Materials and Finish for Concrete Curbs.**—Good work in the construction of concrete curb follows the same general principles as other concrete work. One rather common method, which should not be tolerated, is to build the body of the curb of ordinary concrete and the surface of rich mortar; many curbs so constructed have failed by the separation of the facing from the body. For good work, good concrete should be used throughout.

For a separate curb and a combined curb and gutter, the proportions of materials and sizes of aggregates are varied to suit the character of the work; stones that will pass a $\frac{3}{4}$-inch screen are the largest ordinarily used, but a maximum size of 1 or $1\frac{1}{2}$ inches is also used in some places. A mixture used for first-class work is 1:2:3, but leaner mixtures are also frequently employed. The coarse aggregate is sometimes entirely omitted and a $1:2\frac{1}{2}$ mortar is used.

The concrete is deposited between forms of wood or steel. If these are removed after the concrete has hardened to some extent but not entirely, and the surface is gone over lightly and skilfully with calcimine brushes, a good surface may be obtained. A plastered curb is sometimes constructed by plastering a thin coat of mortar or neat cement onto the inside of the face forms and then depositing the concrete; in a combined curb, the gutter is plastered after the concrete is struck off. However, such plastering should not be allowed because the thin coat is likely to peel and craze. By crazing is meant the appearance of a net-

work of very fine hair-line cracks which disfigure the surface even though they do not actually injure the work.

97. **Street Gutters.**—Along each side of a street roadway some kind of open channel must be provided to receive the water from the surface and convey it to a drainage outlet. Deep side ditches, such as are used on country roads, would be unsightly, dangerous, and otherwise impracticable for a city. Instead, the parts of the roadway that are adjacent to each curb are shaped to serve as gutters. These gutters are generally made by continuing the crown of the roadway, but their water-carrying capacity may be increased by using a steeper slope. However, the gutter should always be shallow enough to be available to some extent for driving purposes when it is not full of water. Street gutters are usually constructed of concrete or brick. When brick are used, they are laid with their longest dimension parallel to the curb.

LANDING FIELDS AND RUNWAYS FOR AIRPORTS

REQUIREMENTS OF LANDING FIELDS

98. **Introduction.**—The construction of landing fields and airports is generally carried out under the supervision of the highway engineer. Therefore, he should be familiar with the requirements for the proper layout and construction of airports.

99. **Location of Airports.**—In order to be of greatest service, the airport should be located where it can have dependable communication and transportation facilities with adjacent cities and towns. As it is important for airplanes to take off and land directly into the wind, the landing field should, if possible, be large enough to permit landing in all directions; where this is not feasible, the longest dimension of the field should be in the direction of the prevailing winds. On account of the hazards of flying in a fog, landing fields should not be built in locations particularly affected by such conditions. Also, near large cities smoke is often sufficiently thick to make flying dangerous and the airport should be located where it will be as free as possible from this danger. Other features that must be studied are the

availability of light, power, and water; the possibility of expansion; the trend of air currents and eddies; the topography and soil characteristics; the ease of identifying the field from the air; and the location with respect to lanes of air traffic. To avoid the risk of catching the landing gear of a plane on telephone, light, and power wires, such obstructions should be placed underground near the airport or removed to a safe distance from it.

100. **Size of Airport.**—The size of airports varies from 50 acres to 1,000 acres, but the average airport covers between 100 and 300 acres. The field should be at least large enough for two landing strips 2,500 feet long and 500 feet wide.

101. **Basic Requirements for Certified Airports.**—In order to comply with the requirements of the United States Department of Commerce for certified airports, the following conditions must be observed:

(*a*) *Suitable Field or Landing Area.*—The landing area must be a firm and approximately level field that is provided with suitable approaches, is well drained, and is without obstructions or depressions that present hazards in taking off or in landing; or else there should be provided at least two landing strips 500 or more feet wide and crossing or converging at angles of not less than 60°. The landing strips must permit safe landing under ordinary weather conditions. If the sod or turf is not sufficiently firm and well drained for these purposes, runways should be constructed of crushed rock, slag, asphalt, or some other material, a suitable binder being provided when necessary. Roads should never cross any part of the landing area, regardless of whether a landing strip or an open field is used. No part of the field or landing strip should have a slope of more than 3 inches in 10 feet, which corresponds to a grade of $2\frac{1}{2}$ per cent., and the average slope of the surface should not be more than 2 per cent.

(*b*) *Runways and Drainage.*—Where runways are provided, they should be not less than 100 feet in width. The edges of the runways must be flush with the rest of the landing strip, and the shoulders of the runways must be constructed of some porous material, such as crushed rock or gravel. Adequate drainage

must be provided whether runways are used or the entire field is available for landing. If natural drainage is good, no artificial system is required.

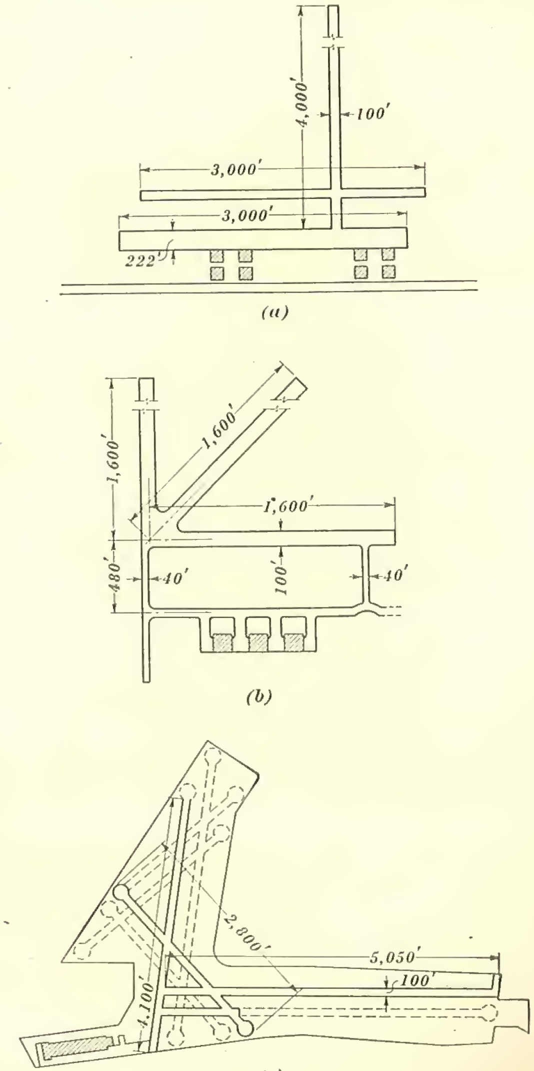
(*c*) *Freedom From Obstacles*.—An obstruction that is near the landing area diminishes the effective dimension of that area by a distance equal to seven times the height of the obstruction. For instance, an obstacle 50 feet high along the border of a field is calculated to diminish the width of the landing area by 350 feet. Where landing strips are provided, the presence of an obstacle in the landing direction of a strip will likewise diminish the available, or effective, length of that strip. However, if an obstacle lies alongside the landing strip, so that a plane passes parallel to and not over the obstacle, the reduction in effective dimension of seven to one will not apply so long as the width of the strip is not less than 500 feet, as previously specified.

(*d*) *Location of Buildings*.—Airport buildings should be arranged along the side of the landing area where they will interfere least with landing and taking off. There should be no buildings or other obstacles at the ends of landing strips or runways. In the larger airports where there is need for a railroad spur or a siding, the tracks should be laid along the rear of the buildings.

(*e*) *Highway*.—The airport must be situated on a good road leading to the nearest town or city.

(*f*) *Wind Indicator*.—The airport must be equipped with an approved type of wind-direction indicator.

(*g*) *Marker*.—The airport must be marked by means of a white or chrome-yellow circle at least 100 feet in diameter. The band forming the circle should be 4 feet wide; it should be constructed of crushed rock, gravel, or other suitable material, and should be placed flush with the ground. In addition, the name of the city or airport must be placed near the marking circle or upon at least one airport building so as to be visible from an altitude of 2,000 feet. Where runways have been installed and by their nature and appearance constitute adequate day marking, no additional identification of these runways or landing strips will be required. If the landing strips are not easily apparent from an altitude of at least 2,000 feet, they should be marked



(c)

FIG. 25

along the borders by means of 4-foot white or chrome-yellow solid circles which are similar to the marker and are not more than 250 feet apart.

102. Typical Airport Layouts.—In Fig. 25 are shown diagrammatically the runways and the buildings at three important airports, namely, the New York Municipal Airport in view (*a*); the Curtiss-Steinberg Airport at East St. Louis, Ill., in view

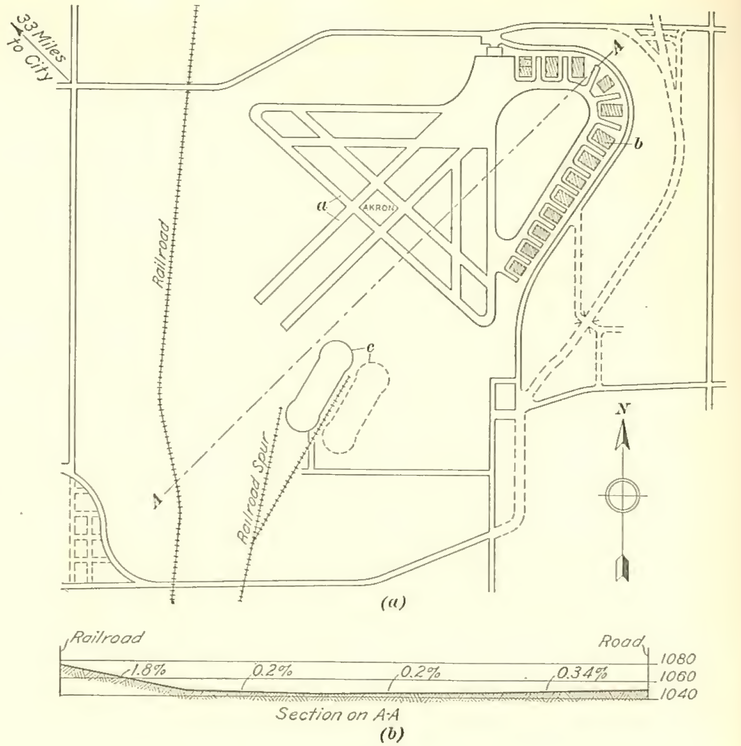


FIG. 26

(*b*); and the Detroit Municipal Airport in view (*c*). The runways represented by the dashed lines in view (*c*) are proposed.

In Fig. 26 (*a*) is illustrated the layout of the airport at Akron, Ohio, and in view (*b*) is shown a profile of the surface along section *A-A* in the plan. The principal facilities of the airport are the runways *a*, the hangars *b* for airplanes, and the two docks *c*—one in place and the other proposed—for Zeppelins, or dirigibles.

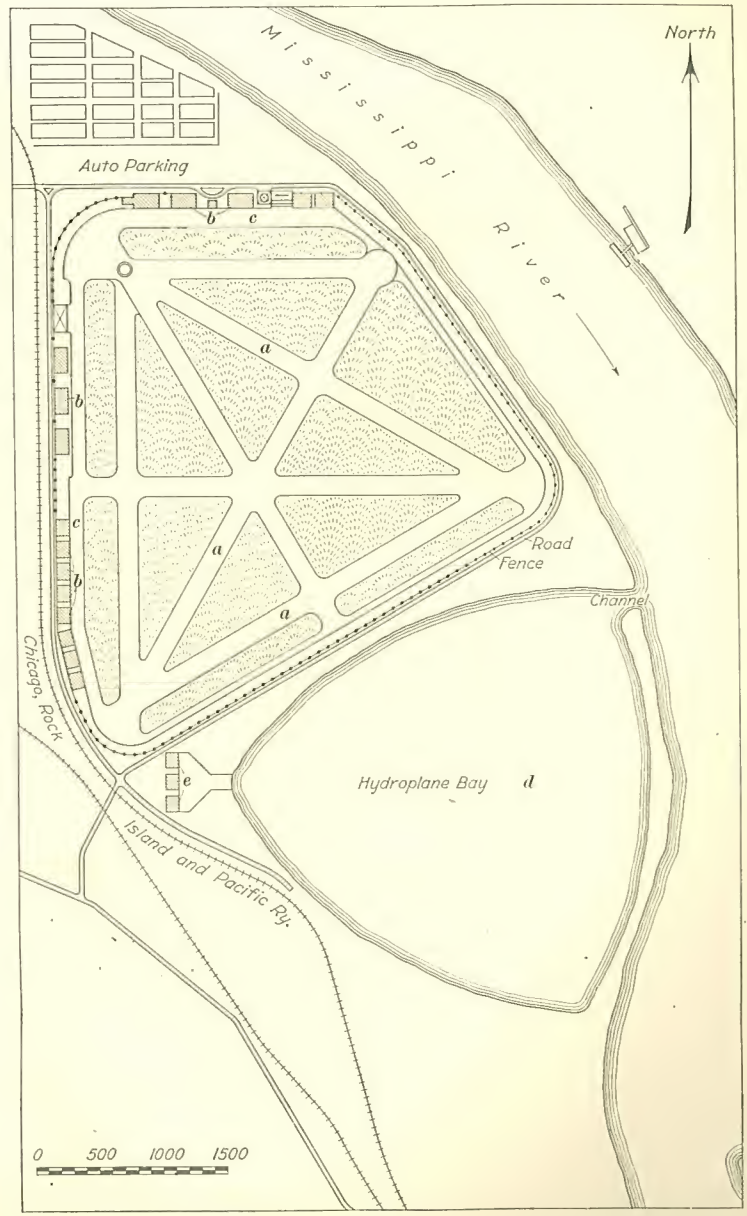


FIG. 27

The proposed ultimate development of the municipal airport at St. Paul, Minn., is shown in Fig. 27. In addition to the paved runways *a*, which are 150 feet wide, and the hangars *b* and aprons *c* for airplanes, there will be a bay *d* and hangars *e* for hydroplanes.

DRAINAGE OF LANDING FIELD

103. Artificial Drainage Systems.—Where the airport is on sand or gravel, it will drain naturally. However, on most fields natural drainage is not sufficient, and artificial drainage must be provided, not only to remove surface water but also to intercept and carry off ground water. For this purpose, tile drains, perforated metal pipe, porous concrete pipe, or stone drains are used in a system of main lines and laterals spaced to fit the soil characteristics. The drains are usually placed at a depth of about $3\frac{1}{2}$ feet in clays and 5 feet in silts, but if deep freezing is expected these depths may be insufficient because drains should extend at least as deep as frost penetration.

104. Size of Drains.—Before designing the drainage system for an airport, rainfall statistics should be obtained in order to determine the probable maximum for the locality. In the United States, the maximum probable rainfall has been determined by the Weather Bureau for periods of 1, 5, 10, and 25 years. The drainage system may be designed to remove in 2 or 3 hours the probable intensity of the hourly rainfall that will not be exceeded more than once a year, but many engineers believe such expense unnecessary and design the drains for the removal of maximum rain within 24 hours. When the rate of rainfall, the time allowed for removal of the water, and the run-off factor are known, it is possible to estimate roughly the quantity of water to be removed.

A formula similar to that given in the Handbook of Culvert and Drainage Practice published by the Armco Culvert Manufacturers Association is

$$Q=\frac{CiA}{T+t} \qquad (1)$$

in which Q = required capacity of drain, in cubic feet per second;
C = coefficient of run-off for ground surface served by drain;
i = rate of rainfall, in inches per hour;
A = estimated area of ground surface served by drain, in acres;
T = duration of rainfall, in hours (assumed 1 hour in airport design);
t = time allowed for removal of rainfall after end of storm, in hours.

The value of C depends on the character of the ground surface. For a paved runway or impervious roof, C may be assumed to be .85 to .9; and for a sodded surface, C may be taken as .2. In case part of the area served by a drain is paved and the rest is sodded, the formula that should be used instead of formula 1 is as follows:

$$Q=\frac{i}{T+t}(C_1A_1+C_2A_2) \qquad (2)$$

in which Q, i, T, and t have the same meanings as in the preceding formula;
C_1 = coefficient of run-off for paved area;
A_1 = extent of paved area, in acres;
C_2 = coefficient of run-off for sodded area;
A_2 = extent of sodded area, in acres.

Where the ground is originally left sodded but is to be paved later, it is advisable to make the initial installation of drains ample to care for the surface run-off that will occur after the pavement has been laid. The size of drain required to discharge the quantity of water Q is determined by applying the principles of hydraulics.

EXAMPLE.—A drain is to serve a portion of a landing field the surface of which consists of 2 acres of roofs and paved runways and 5 acres of sodded ground. The rainfall to be assumed in the design of the drain is 1.5 inches per hour lasting 1 hour, and the water is to be carried away within 3 hours. Also, the coefficient of run-off for roofs and pavements is to be taken as .9 and that for sodded ground as .2. Find the required capacity of the drain.

SOLUTION.—Here $i=1.5$, $T=1$, $t=3$, $C_1=.9$, $A_1=2$, $C_2=.2$, and $A_2=5$. Hence, by formula 2,

$$Q=\frac{i}{T+t}(C_1A_1+C_2A_2)=\frac{1.5}{1+3}(.9\times2+.2\times5)=1.05 \text{ cu. ft. per sec. Ans.}$$

105. Runway Drains.—Unless the soil is porous, underdrains should be placed along the edges of all runways in order to take the surface water away quickly. Otherwise the water would soften the soil just outside the runway and make a dangerous condition for any airplane which might get off the runway. The usual design for these side drains is shown in Fig. 28. The

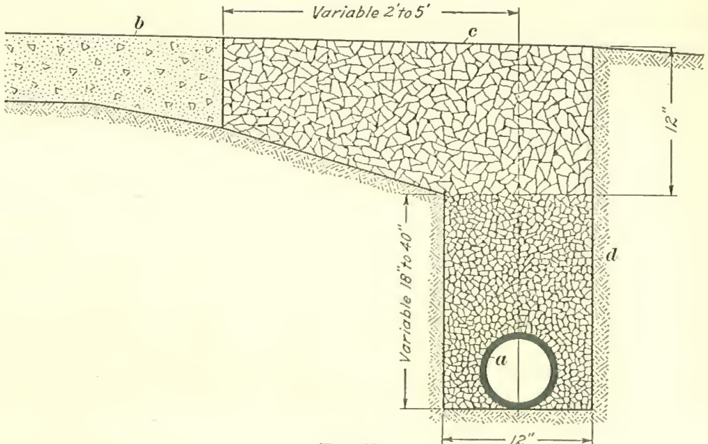


FIG. 28

6-inch drain *a* of vitrified clay, concrete, or perforated metal is placed at the bottom of a trench which is 30 to 52 inches below the surface of the runway *b*. The width of the trench is 12 inches and its center line is 2 to 5 feet from the edge of the runway. The upper part *c* of the backfill, which forms a shoulder that is 12 inches thick over the trench and is tapered so as to meet the edge of the runway, consists of coarse, angular gravel, crushed stone, or slag 2 to 3 inches in size. For backfilling the lower part *d* of the trench, use is made of fine pervious material $\frac{1}{4}$ to $\frac{1}{2}$ inch in size.

SURFACING OF LANDING STRIPS AND RUNWAYS

106. Types of Surfacing Used.—Where the drainage is unusually good, a sodded landing strip may be satisfactory for light planes, but most landing fields will require runways built of some artificial surfacing, especially if heavy commercial planes are to use them. Nearly all the highway types of surfacings have been used for airport runways, including sand-clay, gravel, cinders, slag, crushed stone, bituminous surface treatments, bituminous mixed-in-place treatments, bituminous concretes, portland-cement concrete, and brick. Owing to their size, airport runways are an expensive part of the development, and considerable attention has been given to the use of low-cost types of surfacing similar to those employed for highways. However, on account of the wind action caused by the airplane propeller and the digging action of the tail skid, the untreated low-cost surfacing materials do not prove durable and therefore should eventually be oil-treated or oil processed, or should be used as a base for some type of bituminous topping. Where the soil is somewhat sandy, it may be possible to obtain good results from a mixed-in-place treatment, oil or asphalt emulsion being used in a manner similar to that adopted for roadways. The more common type of low-cost surfacing is an oil-processed gravel, slag, or crushed stone that is mixed in place by harrows and blade graders, as for low-cost road work.

107. Details of Construction of Runways.—In Fig. 29 are shown three typical cross-sections of hard-surface runways. The pavement in view (*a*) was used at the Detroit Municipal Airport and consists of a 5-inch black base *a* and a 2-inch wearing course *b* of asphaltic concrete. At each edge and at the center is a 6-inch drain tile *c*, the trench *d* for which is filled with gravel ranging in size from $\frac{1}{4}$ inch to $1\frac{1}{4}$ inches. A 2″×6″ plank *e* is provided along each edge of the pavement to serve as a form during construction and is left in place.

A single-course plain-concrete pavement, which also was used at Detroit, is illustrated in view (*b*). The slab is 7 inches thick and the crown is inverted, that is, the center is lower than the

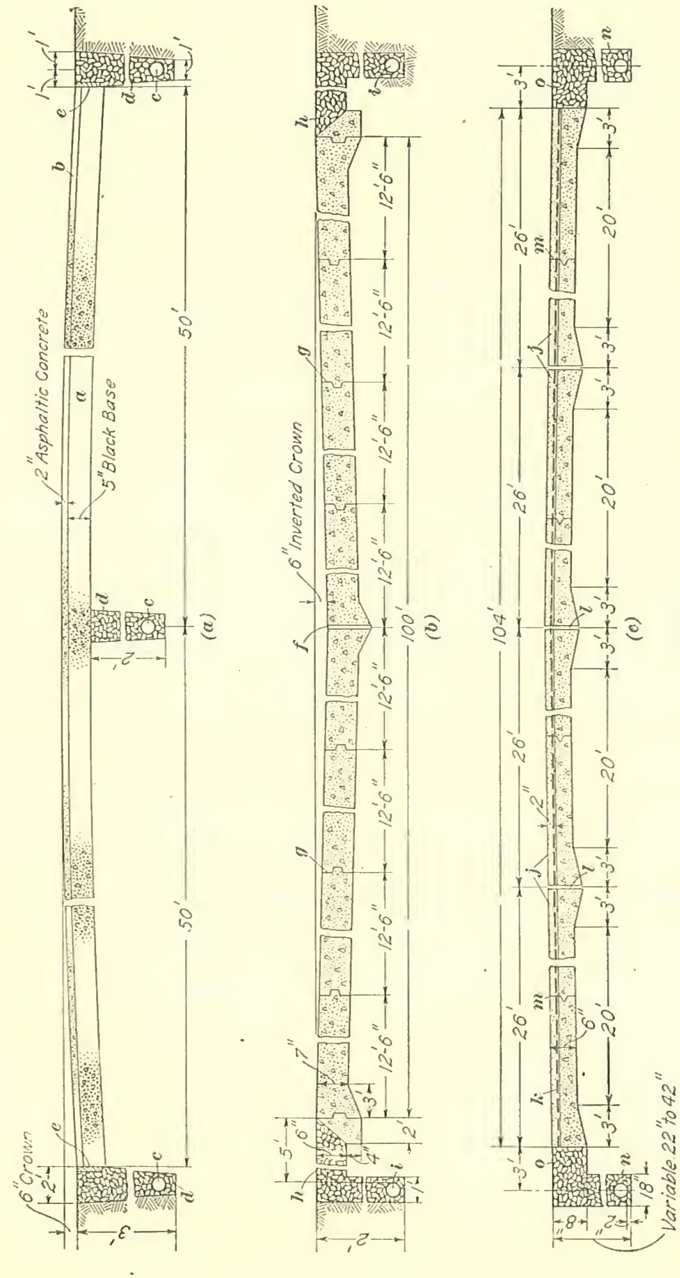


FIG. 29

edges, as in the case of an alley pavement. A $\frac{1}{2}$-inch expansion joint *f* runs longitudinally along the center line, and the 100-foot width is laid in eight strips, each 12 feet 6 inches wide, separated by contraction joints *g*. Also, transverse expansion joints are provided at intervals of 30 feet. Coarse cinders are used for the shoulders *h* and for the backfilling in the trenches for the drain tiles *i*.

In view (*c*) is shown a reinforced-concrete runway laid at the Indianapolis Municipal Airport. The pavement is constructed in four 26-foot strips *j*, each of which has a total thickness of 6 inches at the center and 8 inches at the edges, and is reinforced with wire mesh *k* amounting to 42 pounds per 100 square feet. A longitudinal expansion joint *l*, $\frac{1}{2}$ inch wide, is provided between adjacent strips, and at the middle of each strip is a contraction joint *m*. Also, there is a 1-inch transverse expansion joint every 105 feet and a transverse dummy contraction joint every 35 feet. The lower parts of the trenches *n* for the drain tiles are backfilled with gravel, and the shoulders *o*, which are 8 inches thick, are constructed of crushed stone.

108. At many airports, local materials were utilized in the construction of runways. At the Curtiss Flying Field, Valley Stream, Long Island, there is, in addition to the landing strips, a central circular landing area for instruction flying, on which airplanes can land in any direction. This central area was constructed as follows: A 6-inch layer of local sand, which was found to be coarse enough for the purpose, was spread over the graded area and harrowed with a disk harrow. Then, a first application of a special asphalt was made at the rate of $\frac{3}{4}$ gallon per square yard, and the disk harrow was immediately run over the surface again, not only to mix the sand and asphalt but also to turn the material over and get fresh sand on top for the next application of asphalt. The operations of adding asphalt and harrowing were repeated until a total amount of $2\frac{1}{2}$ to $2\frac{3}{4}$ gallons of asphalt per square yard had been applied. The main mixing was then accomplished with a 12-foot blade grader. The blade was set to make as deep a cut as could be handled and the material was thrown into a windrow, as many cuts as necessary to

turn the full depth of 6 inches being taken. When this operation was completed, the graders respread the material from the windrow in layers until the surface was again smooth. The process of forming a windrow and returning the material to the original position was repeated until the sand and asphalt were thoroughly mixed; for this work at least forty turnings of the mixture were required. After the mixing was finished, the surface was again disk-harrowed to a depth of about 2 inches, and a seal coat of the same asphalt was applied to the loosened material and thoroughly mixed with it by means of the blade grader. This final treatment served to give a better wearing top to the pavement and enabled the surface to be readily resealed under light tamping or rolling. After the surface was leveled with the graders, a light drag was used to even out small irregularities, and an 8-ton tandem roller was employed for the final operation. In order to avoid waves in the finished surface, the rollers were run in two directions at right angles to each other.

For the landing strips outside the central circle, a base course of cinders 3 inches deep was first laid and thoroughly compacted by rolling. Upon the cinders was placed a $1\frac{1}{4}$-inch layer of screened gravel, which was given an application of special asphalt at the rate of $\frac{5}{8}$ gallon per square yard. A second course of gravel $1\frac{1}{4}$ inches in depth was then deposited and treated with asphalt at the rate of $\frac{3}{4}$ gallon per square yard. This was covered with pea-size gravel at the rate of 20 pounds per square yard and the surface was rolled with an 8-ton roller. After sufficient rolling, an asphalt having a penetration of 150 was applied hot at the rate of $\frac{3}{8}$ gallon per square yard and the surface was covered with pea gravel. The total cost of this construction was about 80 cents per square yard.

109. At the airport of Camden, New Jersey, the runways were constructed with a 3-inch base course of cinders and a surface course, also 3 inches thick, of $1\frac{1}{2}$-inch slag penetrated with $1\frac{1}{4}$ gallons per square yard of asphalt at 300° F. The methods of laying the slag and applying the asphalt were similar to those generally used for penetration-macadam roads. Stone chips up to $\frac{3}{4}$ inch in size were spread at the rate of 35 pounds

per square yard and the material was thoroughly compacted with an 8-ton tandem roller. A seal coat of cut-back asphalt was then applied at the rate of $\frac{1}{2}$ gallon per square yard; this was covered with stone chips at the rate of 30 pounds per square yard and the surface was again rolled. Finally, in order to prevent the raising of stone chips by the wind force from the airplane propellers, a special grade of asphaltic oil was applied at the rate of .4 gallon per square yard.

110. In constructing the runways at Los Angeles, California, fine gravel was added to the local sand and the materials were mixed with 3.2 gallons per square yard of asphalt applied in successive treatments. The sand, gravel, and asphalt were thoroughly manipulated by means of harrows and blade graders, and the surface was leveled off with a long-base drag and rolled lightly.

At Jacksonville, Florida, the base course for each runway consisted of a 6-inch layer of local shell. A treatment of asphalt amounting to $\frac{1}{3}$ gallon per square yard was applied to the surface and over this was spread a covering of cinders.

At Roosevelt Field, Long Island, runways were built with crushed stone and emulsified asphalt applied at the rate of $2\frac{1}{2}$ gallons per square yard.

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